

FINAL PROJECT

THE UTILIZATION OF GLASS POWDER AS PARTIAL REPLACEMENT MATERIAL FOR THE MECHANICAL PROPERTIES OF CONCRETE

**Submitted to Universitas Islam Indonesia Yogyakarta in Fulfillment for
Bachelor of Civil Engineering**



By
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**CIVIL ENGINEERING INTERNATIONAL PROGRAM
FACULTY OF CIVIL ENGINEERING & PLANNING
UNIVERSITAS ISLAM INDONESIA
YOGYAKARTA
2024**

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Name : Jafar, ST., MT.

Date: 12 June 2024

APPROVAL

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AUTHENTICITY STATEMENT

I declare in fact that the Final Project report that I prepared as a requirement for the completion of the Bachelor program in the Civil Engineering Study Program, Faculty of Civil Engineering and Planning, Universitas Islam Indonesia is my own work. Certain parts of writing the Final Project report that I quoted from the work of others have been written in the source clearly in accordance with the norms, rules, and ethics of writing scientific papers. If in the future it is found that all or part of this Final Project report is not my own work or there is plagiarism in certain parts, I am willing to accept sanctions, including the revocation of my academic degree in accordance with applicable legislation.

Yogyakarta, 12 June 2024

Author,

Oqbah Ali Mohammed Abdo Qasem

DEDICATION

This final project is presented to God Almighty Allah SWT as a form of worship of the author as His servant, to both parents of the author who continue to provide moral and material support to the author, as well as all parties who have accompanied the author's learning process during my strata-1 education.

FOREWORD

Bismillahirrahmanirrahim

Assalamualaikum Warahmatullahi Wabarakatuh

***Asyhadu Alla Ilahailallah Wa Asyhadu Anna Mohammedarrasulullah
Allahuma Shalli'ala Mohammed Wa'ala Alihi Washobihi Wasalam,***

Alhamdulillahhirrobbil'alamiin, all praise and gratitude I pray for the presence of Allah SWT for the blessing of his mercy and favor, the author was able to complete the final project proposal. Shalawat and greetings also did not forget to pour out on the great prophet Mohammed SAW. The author would like to express his gratitude to all parties who helped and supported in the preparation of this final project, especially to:

1. Jafar, ST., MT. As supervisor fot this final project.
2. Parents and families for all the attention, support, and passion given.
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Wassalamualaikum Warahmatullahi Wabarakatuh

Yogyakarta, 12 June 2024

Author,

Oqbah Ali Mohammed Abdo Qasem

LIST OF NOTATIONS AND ABBREVIATIONS

ASR	= Alkali-Silica Response
ASTM	= American Standard Testing and Material
CH	= Calcium Hydroxide
GP	= Glass Powder
MPA	= Megapascal
OPC	= Ordinary Portal Cement
UII	= Universitas Islam Indonesia
WGP	= Waste Glass Powder

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ABSTRACT

The waste glass powder is used in concrete due to its pozzolanic reactivity, which can improve the microstructure of the paste and enhance the strength and durability of the concrete in the long term. Additionally, waste glass powder can contribute to the refinement of the pore structure, leading to increased resistance to chloride penetration and water permeability in concrete. The objective of this study is to identify the effect of glass powder on the compressive strength, tensile strength, and modulus elasticity of concrete, and to identify the optimum percentage of glass powder that maximizes the mechanical properties and durability of concrete without compromising its workability.

The type of glass powder is green glass and collected from Pabrik Penggilingan beling. The dimensions of concrete samples for compressive strength, tensile strength, and modulus elasticity in cylindrical specimen forms are 30 cm x 15 cm for all the specimens.. This mix design incorporates six different ratios using SNI-03-2834-2000 of glass powder, fine aggregate, coarse aggregate, cement, and water from 0% to 30%.

The effect of Glass powder can improve the mechanical properties of concrete by the means of pozzolanic activity. The test results showed that the tensile strength, and modulus elasticity (MOE) decreased with the increase of GP Content. The optimum percentage of glass powder is 20% that maximizes the mechanical properties and durability of concrete without compromising its workability. There is a strong increase because of the pozzolan glass waste powder is a material containing silica and alumina, the compound will react chemically with calcium hydroxide at room temperature and form compounds that have properties like cement.

Keywords: Compressive Strength, Glass Powder, Modulus of Elasticity, Tensile Strength

CHAPTER I INTRODUCTION

1.1 Background

The waste glass powder is used in concrete due to its pozzolanic reactivity, which can improve the microstructure of the paste and enhance the strength and durability of the concrete in the long term. Additionally, waste glass powder can contribute to the refinement of the pore structure, leading to increased resistance to chloride penetration and water permeability in concrete. This makes it an attractive option for sustainable and high-performance concrete production (Hongjian, 2014).

Glass powder is a byproduct of the glass manufacturing industry and has been increasingly used as a cement substitute in concrete production. The addition of glass powder to concrete offers several benefits, including improved performance and reduced environmental impact. Glass powder can exhibit favorable pozzolanic reactions in concrete, reducing alkali-reactivity and replacing up to 30% of cement with satisfactory strength growth. This sustainable alternative not only conserves natural resources but also saves money on waste disposal. Experimental investigations have shown that concrete with glass powder maintains comparable compressive and split tensile strength to ordinary concrete, making it a viable and environmentally friendly option for concrete production (Kumar, 2022).

The use of glass powder in concrete offers several advantages. Research has shown that glass powder can increase the compressive strength of concrete due to its pozzolanic activity and ability to provide additional hydration sites for cement particles. Fine glass particles act as filler material, enhancing the mechanical properties of the concrete. Additionally, when waste glass is milled to a fine powder, it can undergo a positive pozzolanic reaction, strengthening the concrete while depleting the alkali. These properties make glass powder a promising material for enhancing the performance of concrete in various construction applications (Edward et al., 2020).

The use of glass powder in concrete serves several purposes. Firstly, it can potentially improve the compressive strength of the concrete, as indicated by studies showing that the incorporation of glass powder can lead to higher compressive strength compared to normal concrete. Additionally, the use of glass powder in concrete offers a sustainable solution for utilizing local waste in the form of recycled glass bottles, making it an environmentally friendly alternative to traditional concrete materials. Furthermore, the small grain size of glass powder can fill the pores in the concrete, potentially enhancing its overall strength. While it is not inherently wrong to not use glass powder in concrete, its incorporation offers potential benefits in terms of strength improvement and waste reduction. However, the decision to use glass powder in concrete should consider factors such as the availability of recycled glass, cost-effectiveness, and the specific requirements of the concrete application (Bimantara et al., 2023).

The use of waste glass powder as a partial replacement for cement in concrete production will lead to improved mechanical properties and durability of concrete structures, as well as reduced environmental impact, due to the pozzolanic reactivity and fine particle size of the glass powder. Further research is needed to determine the optimal replacement levels for cement with waste glass powder and to explore its combined use as a replacement for both cement and fine aggregate in concrete production (Pashtoon et al., 2022).

Normal concrete is made with ordinary Portland cement and does not contain any additional materials or additives. It is the most used type of concrete in construction projects. Normal concrete has a typical compressive strength of 20-40 MPa (megapascals) after 14 days of curing (Kumar, 2022). Normal concrete, also known as reinforced concrete (RC), is a widely used construction material composed of a mixture of cement, aggregates (such as sand and gravel), water, and reinforcement (typically steel bars or rebars). It is the most common type of concrete used in building and infrastructure projects due to its strength, durability, and versatility. The production of normal concrete involves several stages, including material production, construction, operation, and dismantlement/disposal. The material production stage, which includes the

manufacturing of cement and the production of concrete components, is particularly important in terms of environmental impact. Overall, normal concrete is a widely used construction material due to its strength, durability, and versatility. However, its production and use contribute significantly to global warming and environmental impact, particularly during the material production stage. Therefore, it is important to understand and assess the embodied GWPs of normal concrete and explore alternative materials and construction methods to reduce its environmental footprint (Hyunsik, 2023).

1.2 Problem Formulation

Specific research questions that could be addressed include:

1. What is the effect of glass powder on the compressive strength, tensile strength, and modulus elasticity of concrete?
2. What is the optimum percentage of glass powder that maximizes the mechanical properties and durability of concrete without compromising its workability?

1.3 Research Objectives

Based on the formulation of the problem above, the research objectives are as follows:

1. To study and analyze the impact of different glass powder percentages on concrete's compressive strength, tensile strength, and modulus of elasticity.
2. Identify the optimal glass powder percentage for maximizing mechanical properties and durability in concrete, while preserving workability.

1.4 Research Benefits

The benefits that will be achieved based on the research objectives are specially for architect and civil engineering professionals, as follows.

1. Glass powder can be used to improve concrete's mechanical and durability properties. This could lead to the development of concrete materials with higher strength, toughness, and resistance to cracking and deformation.

2. Improved compressive strength: Glass powder can help to improve the compressive strength of concrete. This can lead to the development of stronger concrete structures, which can be used to support heavier loads and have a longer lifespan.
3. Improved tensile strength: Glass powder can also help to improve the tensile strength of concrete. This can make concrete more resistant to cracking and deformation, which is important for applications such as roads and bridges.
4. Improved durability: Glass powder can help to improve the durability of concrete by making it more resistant to frost damage, sulfate attack, and other environmental factors. This can lead to longer-lasting concrete structures that require less maintenance.
5. Improved modulus elasticity: Glass powder improves concrete's modulus of elasticity through multiple mechanisms. By filling voids, reacting with calcium hydroxide, and refining the microstructure, glass powder creates a denser, stiffer, and stronger concrete.

1.5 Research Limitation

To focus on the research objectives, there are some research limitations as follows.

1. The type of glass powder is green glass and collected from Pabrik Penggilingan beling.
2. The dimensions of concrete samples for compressive strength, tensile strength, and modulus elasticity in cylindrical specimen forms are 30 cm x 15 cm for all the specimens.
3. The sample production is in Construction Material Laboratorium UII.
4. The sample strength test is in Construction Material Laboratorium UII.

CHAPTER II LITERATURE REVIEW

2.1 Glass Powder in Mechanical Analysis

Harish et al., (2016) conducted an experiment using a glass crusher partially replacing cement to investigate the partial replacement of cement by glass waste powder with a size of 150 microns and 300 microns. glass powder for both 150 microns and 300 microns each was replaced by 10%, 20%, 30% and 40% compared to ordinary concrete containing 0% glass powder.

The materials that were used in this experiment are ordinary Portland cement of grade 43 throughout the work, fine aggregate with a maximum size of 4.75 MM was used, coarse aggregate of granite stone was used and its size was 20 mm and passes through 16 mm , natural water was used that does not contain any additional substances, glass waste powder was used from waste available in local stores and was ground to the required size less than 150 microns and 300 microns and it was found that the specific weight of glass powder is 2.69 is considered a much lower value than the specific gravity of Portland Cement, which is equal to 3.15, As for the glass powder, it was not added to the cement directly, but it was added to the cement before dry mixing with other materials. The superplasticizer was also added to the cement with a percentage of 0.5%. The type of plasticizer is (konplast SP-430).

In this experiment, some tests were done, namely compressive strength, tensile strength, and flexural strength. Samples of the same size were used 150*150*150 the test was carried out at a pressure estimated at 2000 KN and the compression force was calculated using this equation

$$F=P/A \quad (2.1)$$

Where:

F: the compressive strength is negligible in MPA

P: the maximum load applied to the sample

A= Cross sectional area of the specimen (in mm²) = 22500 mm²

It was concluded from the work of the following compressive strength test: in ordinary concrete containing 0% glass powder, a compressive strength equal to 24.70 MPA was obtained, while in other samples containing 10%, 20%, 30% and 40% glass powder, these results were obtained, respectively, at 10%, at a glass powder volume less than 150 microns, a compressive strength equal to 25.72 MPA was obtained, while at a glass powder volume less than 300 microns, 23.544 MPA concrete compressive strength, While at 20% of the glass powder at a volume of less than 150 microns, a strength equal to 26.14 MPA was obtained, while at a volume of less than 300 microns, a concrete compressive strength equal to 22.962 MPA was obtained , While when using 30% of glass powder at a volume of less than 150 microns, 28.194 MPA was obtained and at less than 300 microns, 20.87 MPA concrete compressive strength was obtained, while when using a glass powder ratio equal to 40%, a concrete compressive strength equal to 26.012 MPA was obtained at a volume of less than 150 microns, while at a volume of less than 300 microns, a concrete compressive strength was obtained the strength is equal to 18.166 MPA and 3 molds were used for each sample .

For the tensile strength test, cylindrical-shaped samples with a diameter of 150 mm and a length of 3000 mm and JJ were used. the pressure machine was tested at a capacity of 2000 KN, and this equation was used to calculate the tensile strength:

$$F=2P/\pi DL \quad (2.2)$$

Where:

F = Tensile Strength Of Concrete In MPA

P= Load At Failure In Newton units

L = Length Of The Cylindrical Sample in MM

D = Cylindrical Sample Diameter In mm unit

It was deduced from the action of tensile strength for ordinary concrete, a tensile strength equal to 1.98 MPA was obtained, while for samples containing glass powder, for a sample containing 10% of glass powder, a tensile strength equal to 2.03 MPA was obtained at a glass powder volume less than 150 microns, while at a volume less than 300 microns, a tensile strength equal to 2.21 MPA was obtained, while at 20% of glass powder the tensile strength is equal to 2.12 MPA at a size less than 150 microns, while at a size less than 300 microns, a tensile strength equal to 2.03 MPA was calculated , Whereas, when using 30% of glass powder, a tensile strength equal to 2.26 MPA was obtained at a glass volume less than 150 microns, while at a volume less than 300 microns, a tensile strength equal to 1.90 MPA was obtained, while when using 40% of glass powder, a tensile strength equal to 1.56 MPA was obtained at a volume less than 150 microns, while at a volume less than 300 microns, a tensile strength equal to 1.48 megapascals.

It was deduced from the action of flexural strength on concrete as follows: for ordinary concrete, a flexural strength equal to 6.94 MPA was obtained, while for samples containing glass powder, for a sample containing 10% of glass powder, a flexural strength equal to 6.98 MPA was obtained at a glass powder volume less than 150 microns, while at a volume less than 300 microns, a flexural strength equal to 6.95 MPA was obtained, while at 20% of glass powder flexion is equal to 7.02 MPA at a volume of less than 150 microns, while at a volume of less than 300 microns, a flexion force was calculated equal to 5.40 MPA , Whereas, when using 30% of glass powder, a flexural strength equal to 6.24 MPA was obtained at a glass volume less than 150 microns, while at a volume less than 300 microns, a flexural strength equal to 6.20 MPA was obtained, while when using 40% of glass powder, a flexural strength equal to 5.34 MPA was obtained at a volume less than 150 microns, while at a volume less than 300 microns, a flexural strength equal to 4.85 megapascals .

The addition of glass powder demonstrated varied effects on strength metrics. The most significant enhancement was observed when using 30% glass powder volume with particles less than 150 microns, resulting in a compressive strength of 28.194 MPa and a tensile strength of 2.26 MPa. However, higher glass powder percentages and larger particle sizes led to diminishing strength, evident in a reduction to 18.166 MPa in compressive strength and 1.48 MPa in tensile strength at 40% glass powder volume with particles less than 300 microns.

In terms of flexural strength, variations were noted, reaching a maximum of 7.02 MPa at 20% glass powder volume with particles less than 150 microns and decreasing to 4.85 MPa at 40% glass powder volume with particles less than 300 microns. The findings underscore the importance of carefully considering both glass powder percentage and particle size to optimize concrete strength while effectively incorporating waste glass into concrete production.

In conclusion, the study highlights the potential for improving concrete properties through the judicious use of glass waste powder. However, a nuanced approach is essential to balance the positive effects observed at certain concentrations and particle sizes with the diminishing strength at higher levels. The research suggests the need for further investigation to refine the application of glass waste powder, ensuring its sustainable and efficient integration into concrete formulations (Harish et al., 2016).

2.2 Glass Powder in Workability

Kumar (2022) found that the use of glass powder has the potential to improve both the workability and compressive strength of concrete. Therefore, they studied the utilization of glass waste. The powder was partially replaced by cement at 0%, 5%, 10%, 15%, 20%, 25%, and 30%. % Portland cement type I was used and a specific gravity of 3.16 was used to cast samples for experimental work.

The type of glass from broken windows was used and was crushed before being added to the concrete. Sieve sizes were used as follows: 300 micrometers, where 100% of the glass powder passes through it, 150 micrometers, where 24% of the glass powder passes through it, 75 micrometers, where 73% of the glass powder

passes through it, and less than 75 micrometers, where 73% of the glass powder passes through it. % of glass powder Fine aggregate with a maximum size of 4.75 mm and a specific gravity of 2.60 was used, and coarse aggregate with a maximum size of 10 mm with a specific gravity of 2.82 was used. Sieves of different sizes were used for fine and coarse aggregate. A sieve with a size of 10 mm was used, so the passage rate for coarse aggregate and fine aggregate was 100%, respectively. A 4.75 mm sieve was used, so the passage rate for coarse aggregate was 95.77%, while for fine aggregate the passage rate was 100%. A 2.36 mm sieve was used, so the passage rate for coarse aggregate was 75.57%, while for fine aggregate it was 85%, and a 1.18 mm sieve was used. The passage rate for both coarse and fine aggregate was 65.2% and 56%, respectively. A 0.6 mm sieve was used. The passage rate for coarse and fine aggregate was 29% and 30%, respectively. A 0.3 mm sieve was used, so the passage rate was for both coarse and fine aggregate. They are 10% and 13%, respectively. A sieve size of 0.15 mm was used, so the percentage of passage for the coarse and fine aggregate was 6% and 3%, respectively.

Concrete mixtures are designed with a constant weight-to-weight ratio of 0.32 and 1:1.5:3 cement: sand: gravel. The percentage of glass powder was used at 0%, 10%, 15%, 20%, and 25%. Compressive strength (at 28 and 90 days of age), flexural strength, modulus of elasticity, and absorption tests were performed. Several tests have been conducted in this experiment Compressive strength: The compressive strength of concrete was estimated at a rate of up to 20% without using glass powder, that is, at a percentage of 0%, while with the use of glass powder at a percentage of 10%, 15%, 20%, and 25%. At the age of 14 days, the percentage of compressive strength reached 25.92%, 44.34%, 55.72%, and -14.65%, respectively.

The highest percentage of compressive strength was obtained when using 20% of glass powder at the age of 14 days. The highest percentage of compressive strength was obtained when using 15% of glass powder at the age of 90 days, while when using 25% of the glass powder percentage, low compressive strength was obtained at both ages of 28 and 90 days.

Tensile strength is the flexural tensile strength was found to be 18.64%, 33.36%, 20.64%, and 9.80% when using glass powder with 10%, 15%, 20%, and

25% of glass powder, respectively. The modulus of elasticity is the elasticity test was concluded when a percentage of glass powder was used at 10%, 15%, 20% and 25%, and elasticity of 4.42%, 3.28%, -0.52 and 1.4% was obtained, respectively. At 0% of glass powder, elasticity was obtained. An elasticity of 19,752 MPa was obtained. At 10% of the glass powder, 20,652 MPa of elasticity was obtained. At 15% of the glass powder, 20,400 MPa was obtained. At 20% of the glass powder, 20,392 MPa was obtained. At a rate of 25% of using glass powder, an elasticity of 19,752 MPa was obtained. Obtaining an elasticity factor of 19650 MPa.

Absorption test is the absorption percentage test was concluded for all glass powder samples, and it gave a lower absorption percentage compared to the sample that did not contain glass powder. It gave a higher absorption percentage, as at 0% of glass powder, an absorption of 1.0351% was obtained, while with glass powder at rates of 10%, 15%, 20% and 25%, an absorption rate of 0.875%, 0.76%, 0.72% and 0.67% was obtained, respectively. The study yields a significant conclusion that incorporating glass waste into concrete offers notable advantages. One key finding is the potential reduction in cement usage, resulting in cost savings and environmental benefits. This reduction aligns with sustainable practices by repurposing waste materials and minimizing the environmental impact associated with cement production.

Moreover, the research demonstrates that the use of glass powder as a partial replacement for cement in concrete enhances several crucial properties. The study considered varying percentages of glass powder (10%, 15%, 20%, and 25%) and observed improvements in concrete strength and modulus, coupled with a reduction in water absorption. These enhancements were particularly pronounced up to a 20% glass powder content, as evidenced in both compacted and flexural concrete, as well as in the modulus of elasticity. This suggests that the judicious use of glass waste contributes to improved concrete performance.

Considering these findings, the study emphasizes the dual benefits of utilizing waste glass in concrete—improved concrete properties and positive environmental impacts. By presenting a viable alternative to traditional concrete formulations, this research contributes to the ongoing efforts to create more sustainable and

environmentally friendly construction practices. Further exploration and application of these findings could pave the way for more widespread adoption of glass waste in concrete production (Yassen et al., 2019).

2.3 Glass Powder as Partial Substitute

Khalil et al., (2018) investigated the effect of waste glass powder as a partial substitute for reinforcement on some properties of cement. They used different percentages of waste glass, which are as follows: they used percentages of 10%, 15%, 20%, 25%, and 30%. The test was conducted to study the properties of concrete, such as density. Compressive strength, tensile strength, elasticity factor and bending strength. The materials that were used in this experiment were ordinary Portland cement of the first type, and fine natural aggregate was used, where the maximum size of the aggregate is 4.75 mm, with screen sizes of 10 mm, 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, and 0.15 mm. mm, so the percentage of passage of fine aggregate was 100%, 100%, 88%, 78%, 56%, 19%, and 5%, respectively. Natural coarse ground aggregate was used with a maximum size equal to 14 mm with a sieve size of 14 mm, 10 mm, and 5 mm, so the percentage was the passage of fine aggregate is 100%, 72% and 0% respectively. Natural potable water was used in the concrete. 0.5-2.5 liters/100 kg of cement was used. Glass powder waste was used. Window glass waste type was used. The fineness of the glass powder was checked, and it was equal to 7340 cm²/g. It was checked according to (ASTM C-204 (Blain method)). The duration of grinding the glass took 10 minutes.

The mixing process is completed in a rotary electric mixer with a capacity of 0.1 m³. For the concrete mix that contains glass waste, the coarse and fine aggregate are mixed for one minute, while the glass powder and cement are mixed by hand for five minutes, then water is added to it at a rate of 60% of the mixing water and mixed for a minute. The superplasticizer is mixed with 40% of the remaining water. Mixing, then added to the mixture and mixed for two minutes. After that, the molds were cleaned, and their surfaces lubricated. Then the concrete was placed in the molds and compressed with a vibrator to remove any trapped air. After that, it was

left for 24 hours. After that, the bottles were removed from the molds and immersed in water containing 3 g/liter of Calcium hydroxide.

After that, a compressive strength test was carried out in accordance with BS 1881. The test was carried out in 100 mm concrete cube specimens. Three samples were recorded at the age of 60 days. The tensile strength was tested according to ASTM C 496. The average split tension for three cylinders was 200 mm. Height and 100 mm diameter at an age of 60 days, and the flexural strength was tested according to STEC 78 at an average modulus of rupture for three prismatic specimens of size 100 mm 300mm height with 150mm diameter at 60 days old.

As for the compressive strength, when using 0% of glass powder, a compressive strength of 64.7 MPa was obtained at the age of 60 days, while when using a percentage of 10% of glass powder, a compressive strength of 66.1 MPa was obtained, and when using a percentage of glass powder, a compressive strength was obtained. 73.3 MPa Panama at 20%, 25% and 30%, compressive strengths equal to 63.5 MPa, 60 MPa and 58.4 MPa were obtained, respectively.

As for the tensile strength at 10%, 15%, and 20%, the tensile strength increased by 4.1 MPa, 5.41 MPa, and 4.89 MPa, respectively, compared to ordinary concrete, which has a tensile strength of 3.97 MPa, while at the glass powder percentage of 25% and 30%, strength was obtained. Tensile strength of 3.52 MPa and 3.21 MPa, respectively, compared to normal concrete. Regarding flexural strength, the highest flexural strength was obtained at 15% of glass powder, which was 7.65 MPa at the age of 60 days, while at 10%, 20%, 25% and 30% it flexural strength of 6.34 MPa, 5.75 MPa, 4.98 MPa, and 4.61 MPa, respectively, compared to ordinary concrete, which has a flexural strength equal to 5.68 MPa, respectively. Therefore, it was found that the concrete has a flexural strength at a glass powder percentage of 15%.

While the modulus of elasticity at a percentage of 15% of glass powder was 48.8 kN/mm², while at a percentage of glass powder of 10%, 20%, 25% and 30%, an elastic modulus of 46.9 kN/mm², 46.6 kN/mm² and 43.7 kN/mm² was obtained. /mm² and 41.53 kN/mm², respectively. Therefore, it was found that the optimum is the one that contains a glass powder percentage of 15%.

The test results reveal that incorporating waste glass powder as a partial replacement for fine aggregate holds promise for enhancing certain properties of concrete. Notably, the compressive strength reached its highest value at 20% replacement, achieving 73.3 MPa. However, diminishing compressive strength was observed at higher replacement percentages (25% and 30%).

In terms of tensile strength, a substantial increase was observed with 10% and 15% replacement of glass powder, reaching 4.41 MPa and 5.41 MPa, respectively. Nevertheless, a decline in tensile strength occurred at higher replacement percentages. The flexural strength exhibited its peak at 15% replacement (7.65 MPa) but decreased at both lower and higher replacement percentages. The highest elasticity modulus (48.8 kN/mm²) was achieved with a 15% replacement of glass powder.

Consequently, the test results suggest that the optimum percentage for glass powder replacement in fine aggregate is 15%. This level of replacement enhances tensile strength, flexural strength, and elasticity modulus without significantly compromising compressive strength. The use of waste glass powder as a partial replacement for fine aggregate not only improves concrete properties but also aligns with sustainable concrete production practices.

However, it's crucial to acknowledge that the observed results may be influenced by factors such as the specific type of glass powder and the mixing process. Further research is warranted to validate these findings and assess the long-term performance of concrete incorporating waste glass powder. This ongoing exploration will contribute to a comprehensive understanding of the potential and limitations of utilizing waste glass in concrete production (Khalil et al., 2018).

2.4 Resume of Previous Research Results

In the initial research study conducted by Harish et al., (2016) the investigation focused on the effects of partially replacing cement with glass waste powder of varying particle sizes (150 microns and 300 microns) on concrete properties. The findings revealed that the addition of glass powder, up to 30%, led to an improvement in compressive strength, with the highest peak observed at 30%

glass powder featuring particles less than 150 microns. However, the tensile and flexural strengths exhibited diverse trends based on the percentage of glass powder and the particle size.

The second research, carried out by Kumar (2022), delved into the impact of glass powder (ranging from 0% to 30%) on the workability and compressive strength of concrete. Notably, a 20% replacement yielded the highest compressive strength at 55.72%. Furthermore, the modulus of elasticity demonstrated improvement with an increase in glass powder content, accompanied by a decrease in water absorption.

The third study by Khalil et al., (2018) focused on investigating waste glass powder (in the range of 10% to 30%) as a partial substitute for reinforcement in concrete. Optimal results were achieved with a 20% glass powder replacement, showcasing improved compressive strength (73.3 MPa), tensile strength (5.41 MPa), and flexural strength (7.65 MPa). The elasticity modulus reached its peak at 15% glass powder. Collectively, these studies underscore the potential of waste glass powder as a sustainable additive in concrete, offering benefits in terms of strength, modulus, and environmental impact. Further research is recommended to refine application techniques and ensure the long-term performance of concrete incorporating waste glass powder.

2.5 Application Of Concrete Containing Glass Powder

Based on the previous results, The Concrete containing glass powder can be applied in construction projects as a sustainable and innovative alternative to traditional concrete formulations. The first research study conducted by Harish et al., (2016) focused on partially replacing cement with glass waste powder, demonstrating that specific percentages and particle sizes of glass powder can significantly influence the compressive, tensile, and flexural strength of concrete. The results indicated that careful consideration of the glass powder percentage and particle size is crucial to optimize concrete strength. By incorporating glass waste powder, concrete producers can potentially enhance performance metrics while contributing to the eco-friendly utilization of waste materials.

In another study by Kumar (2022), the researchers emphasized the dual benefits of incorporating glass waste into concrete: cost savings through reduced cement usage and improved concrete properties. The research explored various percentages of glass powder, highlighting that up to 20% content resulted in notable improvements in compressive strength, flexural strength, modulus of elasticity, and reduced water absorption. This study underscores the potential for glass waste to contribute to sustainable construction practices by repurposing waste materials and minimizing the environmental impact associated with cement production.

Furthermore, Khalil et al., (2018) investigated the effect of waste glass powder as a partial substitute for fine aggregate on concrete properties. The study revealed that incorporating glass powder up to 15% replacement in fine aggregate led to enhanced compressive strength, tensile strength, flexural strength, and elasticity modulus. The research suggested that 15% replacement is the optimum level, balancing the improvement of certain properties without significantly compromising compressive strength. This finding supports the idea that waste glass powder can be judiciously used to enhance concrete properties, providing a viable and sustainable alternative for construction projects.

2.6 The Comparison Of Previous Research

Table 2. 1 Previous Research

No	Research's Names and Publication's Year	Materials	Variables	Mix Proportion	Results
1	Harish B A1, Hanumesh B M2, Siddesh T M3 (2016)	1. Glass powder (GP) 2. Super Plasticizer	a. Compressive Strength Test b. Tensile Strength Test c. Flexural Strength Test	1. OPC 2.GP 3.Fine Aggregate 4.Coarse Aggregate 5. Water	The experimental results show that using glass powder as a partial replacement for cement in concrete improved the strengths of concrete (compression and flexural) for glass powder content by up to 20%. Additionally, the absorption percentage decreased with increasing glass powder content. The study also suggests that using waste glass as a powder in concrete has

					environmental benefits and improves concrete properties
2	Yassen1, Mahmoud2 and Hama2 (2019)	Glass Powder	1. Compressive Strength Test 2. Flexural Tensile Strength Test 3. Modulus of Elasticity	1. GP 2. `OPC 3. Fine Aggregate 4. Coarse Aggregate 5. Water	The experimental results indicate that the use of glass waste powder as a partial replacement for cement in concrete can improve its mechanical properties. Specifically, the study found that the compressive, splitting tensile, and flexural strengths, as well as the static modulus of elasticity, were enhanced with the increase of glass waste powder up to 15%.

3	Khalil and Al-Obeidy (2018)	1. Glass Powder 2. Super Plasticizer	1. Compressive Strength Test 2. Flexural Tensile Strength Test 3. Modulus of Elasticity	1. GP 2. OPC 3. Fine Aggregate 4. Coarse Aggregate 5. Water 6. SP	Incorporating waste glass powder in concrete as a partial fine aggregate replacement shows promise. Compressive strength peaks at 20% replacement (73.3 MPa) but decreases at higher percentages. Tensile strength increases notably at 10% and 15% replacement (4.41 MPa and 5.41 MPa), declining at higher replacements. Flexural strength peaks at 15% replacement (7.65 MPa) but decreases at lower and higher percentages. The highest elasticity modulus (48.8 kN/mm ²) is achieved at 15%
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					<p>replacement. Optimal replacement is suggested at 15%, enhancing key properties without compromising compressive strength significantly. This aligns with sustainable concrete practices. However, results may be influenced by factors like glass powder type and mixing process, necessitating further research for validation and long-term performance assessment.</p>
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CHAPTER III THEORETICAL BACKGROUND

3.1 Introduction To The Waste Glass Powder

3.1.1 Waste Glass Powder as Supporting Materials

Waste glass powder is a by-product of the glass recycling process, typically obtained from crushed and ground waste glass. It is a fine, powdery material that can be used as a partial replacement for cement in concrete production. This material is being increasingly explored as a sustainable alternative to traditional cement, with the potential to enhance the strength and durability of concrete while reducing the environmental impact of waste glass disposal (Jyothi, 2020).

Waste glass powder utilized in concrete as a fractional substitution of cement might be a critical step toward the improvement of feasible ecologically neighborly, energy-efficient, and temperate framework frameworks (Zeybek et al., 2022). The waste glass powder offers concoction structure and reactivity for utilize as a supplementary cement fabric which can be a useful point to the substance of strength, clamminess resistance and sturdiness of cement. Supplanted with waste glass powder gives compressive qualities surpassing those of control concrete. Waste Glass Powder (WGP) is found to be bolstered as a crude fabric to make cement clinker in furnace at tall temperature in arrange to decrease antagonistic affect on the in general quality of the created cement (Naamadadin, 2020).

3.1.2 Mechanical Properties

Much research has already discuss about the influence of Waste Glass Powder (WGP) on mechanical properties. Kalkada (2019) conducted an experimental investigation into the impact of using WGP in a high volume (up to 80%) with two different particle sizes (85% <75 mm and 95% <150 mm) on compressive and tensile strength at 7, 28, and 91 days. This research noted similar

compressive strength at 20% substitution for both GP particle sizes at their respective testing ages.

Waste Glass Powder with molecules measuring less than 100 μm comes in pozzolanic reactivity (Tariq et al., 2022). Pozzolanic Glass Powder (PGP) upgrades plastic properties of concrete and concrete quality between 28 and 90 days increments due to the pozzolanic action of PGP. The glass powder might bring approximately the alkali-silica response (ASR) in cement, however the glass powder seems to smother their ASR penchant, an effect like supporting materials for concrete. ASR concerns of glass within the 0.6–1.18 μm run have constrained its broad utilize in concrete. In the final two decades, impressive investigate has been pointed at utilizing glass as pozzolanic fabric, by exploring mechanical, workability, and strength execution (Chen et al., 2020).

The addition of glass powder to concrete has been found to improve its mechanical properties, particularly the compressive strength. This improvement is attributed to both physical and chemical effects. The physical effect involves the adjustment of the granulometry of the cement, increasing the compactness of the paste. Additionally, the chemical effect is due to the pozzolanic reaction of the glass powder with the hydration products of the clinker, forming dense hydrated calcium silicates (C-S-H), which contributes to the increase in compressive strength. The glass powder, with a fineness like that of cement, plays a role in filling and accelerating the pozzolanic reaction, ultimately leading to an increase in strength. However, it is important to note that the increase in strength is limited to a certain percentage of glass powder, beyond which the strength is affected. Therefore, the use of glass powder in concrete improves its mechanical behavior compared to ordinary conditions, but with a limited percentage of 20% of the cement content (A and Kemer, 2023).

The mechanical properties of concrete, such as compressive strength, flexural strength, and bond resistance, are crucial for ensuring the structural integrity and durability of concrete structures. These properties determine the ability of concrete to withstand external forces, such as loads and environmental conditions, without

experiencing failure or deformation. Glass powder with an average particle size of 10 mm exhibited mechanical performance.

3.1.3 Mechanical Properties

The strategy of mixing concrete must meet the ASTM C94 (ASTM, 2020). Waste glass powder in a good workability proportion of around 15 mm at 0%, 10%, and 20% substitutions. Waste glass powder particles were broken into little pieces physically. At that point, glass pieces were powdered employing a planetary ball process at 600 r/min for 20 min. Glass powder with molecule measure less than 100 mm comes about in pozzolanic reactivity, hence as it were WGP less than 75 μ m passed through the sifter 200 was utilized as 20% cement replacement in the mix designs (Chen et al., 2020). A change within the workability and flowability characteristics of the concrete was detailed at all the substitution levels (Tariq et al., 2022). Here's the mix proportion of Glass Powder for and Cement in concrete (Naamadadin, 2020).

Table 3 1 Mix Proportion Of Waste Glass Powder

Specimens	w/c ratio (%)	Glass Powder (Kg)	Cement (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Water (Kg)
Concrete 1	0.5	0.00	1.353	2.554	3.271	0.710
Concrete 2	0.5	0.181	1.296	2.554	3.271	0.710
Concrete 3	0.5	0.272	1.242	2.554	3.271	0.710
Concrete 4	0.5	0.363	1.453	2.554	3.271	0.710
Concrete 5	0.5	0.454	1.596	2.554	3.271	0.710
Concrete 6	0.5	0.545	1.817	2.554	3.271	0.710

Source: Naamadadin (2020)

In this mix design, concrete mixtures are designed with a constant weight-to-weight ratio of 0.5 with a proportion of 1:1.9:2.6:0.54 for each Glass Powder: Cement: Fine Aggregate: Coarse Aggregate: Water. The Waste glass powder was supplanted based on mix design with percentages on 0%, 10%, 15%, 20%, 25%, and 30%. After 24 hours the molds are disassembled, and curing begins. Mix the concrete within the blending skillet with a scoop or trowel to dodge isolation when shaping the test. Concrete scoop or blunted trowel were utilized to tap around the beat surface edge of the mould in arrange to guarantee the symmetrical movement of the concrete and to decrease coarse total isolation interior the shape.

3.2 The Influence Of Waste Glass Powder Used In The Concrete

3.2.1 General Properties

The influence of waste glass powder used in concrete was investigated in an experimental study. The study found that using glass powder as a partial replacement for cement in concrete can have both positive and negative effects on the properties of the concrete. Specifically, higher percentages of glass powder led to reduced compressive strength but improved tensile and flexural strength. The study suggested that using 20% glass powder as a cement replacement may achieve a balance between these properties. Additionally, the use of glass powder as a cement replacement up to 25% fulfilled the limits of Egyptian Portland cement specification, indicating that it can be a viable alternative. Overall, the study concluded that using glass powder as a cement replacement can have positive effects on the strength of concrete, particularly in terms of tensile and flexural strength.(Ahmed G.Elmikass1 et al., 2022). The use of waste glass powder as a partial replacement for cement in concrete production has gained attention due to its potential to mitigate the environmental impact of the glass and cement industries.

Waste glass powder, when used in concrete, can influence various properties of the material, including workability, compressive strength, flexural strength, and split tensile strength. Additionally, the pozzolanic reactivity of glass powders and their impact on the fresh and mechanical properties of concrete have been studied. Overall, research suggests that waste glass powder has the potential to be a

sustainable alternative to cement in concrete production, with the potential to improve the mechanical properties and durability of concrete structures. Further research is recommended to determine the optimal replacement levels for cement with waste glass powder and to explore its combined use as a replacement for both cement and fine aggregate in concrete production (Pashtoon et al.,2022).

The influence of waste glass powder on the properties of concrete can vary based on the percentage of glass powder used in the mix. Some studies have shown that the workability of concrete can increase with the addition of waste glass powder, while others have reported a decrease in workability with higher percentages of glass powder. In terms of strength, it has been found that waste glass powder can be used to replace cement in concrete up to 20% without significant adverse effects on strength. Additionally, the use of waste glass powder in concrete has been shown to have environmental benefits, as it can reduce disposal problems and contribute to the production of environmentally friendly construction materials.

3.2.2 Compressive Strength

The compressive quality of concrete shapes would deliver the information of the concrete potential strength mixture from which it was tested. The compressive strength of concrete was carried out according to ASTM C109. Pozzolanic materials in Water Glass Powder increased the compressive strength smoothly on 14 days, glass powder can be used as cement replacement until 15%, which can be considered as a reasonable amount in producing sustainable concrete (Muhedin, 2023). The formula for calculating the compressive strength of concrete is as follows.

$$\text{Compressive Strength} = \frac{\text{Max Load Carried by the specimen}}{\text{Top surface area of specimen}} \quad (3.1)$$

Compressive strength is particularly important as it reflects the ability of concrete to resist compression and bear heavy loads, while flexural strength indicates its ability to withstand bending and tensile forces. Bond resistance is essential for ensuring the adhesion of concrete to reinforcement materials, such as steel bars, in reinforced concrete structures. The addition of glass powder to

concrete can significantly influence these mechanical properties. Studies have shown that the incorporation of waste glass powder (WGP) in concrete can enhance its compressive strength, flexural strength, and bond resistance. This improvement in mechanical properties is attributed to the pozzolanic reactivity of glass powder, which contributes to the development of strength in concrete.

Overall, the mechanical properties of concrete play a critical role in determining its structural performance and longevity, and the addition of glass powder can be a valuable means of enhancing these properties (Pashtoon et al., 2022).

3.2.2 Tensile Strength

Split Tensile of concrete was tested in compression, according to ASTM C109 to determine the compressive strength and split tensile strength, respectively. Naamadadin et al, (2020) tentatively explored the impact of supplanting 4%, 8%, and 12% of cement with WGP having molecule sizes extending from 3 μm to 60 μm on compressive and tensile quality. They found that utilizing 4% of GP increments the 28-day compressive and tensile quality by 34% and 21%, separately. The formula for calculating the split tensile strength of concrete is as follows.

$$T = \frac{2P}{nLd} \quad (3.2)$$

Where is,

T = Split tensile strength, KPa

P = Maximum applied load indicated by testing machine, KN

L = Length, M

D = Diameter

The tensile strength of the concrete was measured by splitting tensile strength test in accordance with. The average value of three specimens is reported for each test. The strengths were measured after 7, 28, 90, 180, 365, and 545 days of curing. concrete specimens exhibit almost similar performance in splitting tensile strength as that of compressive strength when sand was replaced by WGP. The

strength peaks for 5% replacement percentages and decrease gradually to dip in specimens containing 20% WGP as sand replacement (Muhedin, 2023).

3.2.3 Modulus Of Elasticity

The modulus of elasticity was measured in accordance with ASTM C469. Patel et al., (2020) inspected the affect of up to 20% WGP utilize with two closely particulate sizes (75 μ m and 63 μ m) on a few concrete qualities such as compressive, tensile, modulus elasticity. Comes about from their ponder appeared that the quality picks up in terms of compressive, tensile, and flexural pliable quality is dynamic up to 20% substitution level, whereas no significant alter within the modulus elasticity of WGP-modified concrete was watched compared to the reference concrete. The formula for calculating the Elasticity Modulus of concrete is as follows.

$$\begin{aligned} E_c &= 57.000\sqrt{f_c'} \text{ lb/in}^2 \text{ in USCS units} \\ &= 4.700\sqrt{f_c'} \text{ MPa in SI units} \end{aligned} \quad (3.3)$$

Where is,

E_c = Modulus of elasticity of concrete, lb/in² (MPa)

f_c' = specified 28-day compressive strength of concrete, lb/in² (MPa)

The lower modulus of elasticity for concrete at higher glass substitution level is credited to the overpowering impact of weakening figure as compared to the advantageous impacts given by the pozzolanic response of glass powder. In expansion, the type of hydration products formed during the pozzolanic reaction could also result in an overall lower elastic modulus. Whatever the GP particles' size, the compressive strength, compression toughness, and elastic modulus of low w/b ratio concrete specimens are relatively higher than those of the high w/ b ratio. The use of GP up to 15% as a cement replacement for both particle sizes tends to decrease the elastic modulus slightly. The slight lessening expanded up to 20% for concrete containing better WGP molecule sizes (Omer, 2023).

3.2.4 Workability

The addition of glass powder to concrete can influence workability. Research has shown that as the percentage of glass powder used as a replacement for cement

increases, the workability of the concrete mix decreases. This is supported by findings that show a decrease in slump values with increasing percentages of glass powder in the concrete mix. Additionally, the use of glass powder as a partial replacement for cement has been found to affect the water demand of the concrete mix, which can further impact workability. These findings are consistent with the results obtained from various trials, which have shown that the workability of concrete decreases as the percentage of glass powder used as a replacement for cement increases. Furthermore, the workability of concrete mixes with glass powder replacements has been found to be influenced by the type of glass powder used, with different types of glass powder showing varying effects on workability.

In summary, the addition of glass powder to concrete as a partial replacement for cement can lead to a decrease in workability, with the percentage of glass powder and the type of glass powder used both playing significant roles in influencing workability (Bhagyashri et al. 2020)

The workability of concrete is essential as it directly impacts the ease of construction and the quality of the final product. Good workability ensures that the concrete can be easily mixed, placed, and compacted without segregation or bleeding, resulting in a dense and durable structure. (Keerio *et al.*, 2017) Workability in concrete can be evaluated using various methods. Some common methods include the slump test, flow table test, and Vebe test. The slump test measures the consistency and workability of concrete by determining the "slump" or the amount the concrete slumps after a specific type of mold is removed. The flow table test measures the flow of concrete by determining the diameter of the concrete spread after being impacted by a flow table.

3.2.5 Weight and Density

The weight and density of glass powder in concrete are important factors to consider due to the pozzolanic behavior of the glass powder. When finely ground waste glass is used in concrete, it can act as a pozzolan, reacting with calcium hydroxide to form additional calcium silicate hydrate (C-S-H) gel. This reaction

contributes to the densification of the concrete matrix, leading to increased strength and durability.

Additionally, the weight and density of the glass powder affect the workability and flowability of the concrete mix. The specific gravity and fineness of the glass powder play a role in determining the overall density of the concrete mix, which can impact its performance and strength characteristics. Therefore, understanding the weight and density of glass powder in concrete is crucial for optimizing the mix design and achieving the desired mechanical properties (Lalitha, 2017).

The density of concrete containing glass powder is affected due to the high silica content of glass, which chemically reacts with alkalis in cement to form a cementitious product, contributing to strength development. Additionally, waste glass powder effectively fills the voids, resulting in a dense concrete microstructure and offering resistance against expansive forces caused by sulphates and penetration of sulphate ions into the concrete mass. The use of finely divided glass powder as a cement replacement material has yielded positive results in terms of density and strength development (Srikanth Maheshwaram & Harikrishna Damera, 2017). Calculate the minimum index density ($Y_d(\min)$) as follows:

$$Y_d(\min) = \frac{W_s}{V_c} \quad (3.4)$$

Where:

W_s = Weight of tested

V_c = Calibrated volume of the mold

Calculate the maximum index density ($Y_d(\max)$) as follows:

$$Y_d(\max) = \frac{W_s}{V} \quad (3.5)$$

Where:

V = Volume of tested

V_c — ($A_c \cdot H$)

A_c = the calibrated cross-sectional area of the mold

H = height of sample reduced in the mould due to vibrations.

The density of concrete is influenced by factors such as the type and proportion of aggregates, the water-cement ratio, and the incorporation of supplementary materials such as glass powder. As the density of the concrete decreases, its weight also decreases. The incorporation of glass powder in concrete can lead to a decrease in density. Research has shown that the density of concrete decreases with an increase in the percentage of waste glass powder used in the concrete mix. This is attributed to the lower specific gravity of glass powder compared to cement, leading to a reduction in the overall density of the concrete.

Furthermore, the workability of concrete, which is a mechanical property, can also affect its density and weight. As the workability of concrete increases, the density of the fresh concrete mixes decreases, resulting in a lower weight of the concrete (Malbila *et al.*, 2022). The density of concrete is influenced by various factors, including curing time, hydration products, and the presence of glass powder (GP) as a cement substitute. As the curing time increases, the concrete density also increases due to the generation of more hydrate products, resulting in a loss of voids and porosity. However, the density of concrete decreases with an increase in GP content, attributed to the loss of extra free water, reduction in cement ratio, and the higher specific gravity of cement compared to glass powder. Additionally, the pozzolanic reaction of GP with calcium hydroxide (CH) leads to the production of more CSH gel, which decreases porosity and strengthens the concrete at a later age, ultimately increasing the density.

The new mixing technique, which involves GP immersion in water before adding it to the dry concrete components, has been shown to enhance workability and produce approximately the same densities at 5% and 20% GP ratios compared to the conventional mixing method. This improvement in workability is attributed to water bleeding from the GP. Studies have shown that the water absorption of concrete decreases with an increase in GP substitution ratios, as the pozzolanic reaction of GP with calcium hydroxide (CH) leads to the production of more CSH gel, which decreases porosity and strengthens the concrete at a later age, ultimately reducing water absorption. Additionally, the new mixing technique, which involves

GP immersion in water before adding it to the dry concrete components, has been shown to result in a lower absorption ratio at 5% and 20% GP proportions, contributing to the decrease in water absorption due to the generation of more hydrate products and the minimization of concrete porosity.(Keerio *et al.*, 2017). The formula for water absorption in concrete is typically calculated using the following equation:

$$\text{Water absorption} = \frac{w_2 - w_1}{w_1} \times 100 \quad (3.6)$$

Where:

W1 = dry weight of sample

W2 = weight of sample after 24 hours of immersion.

3.3 The Optimal Mixture of Waste Glass Powder

Ahmad *et al.*, (2021) discuss about the optimal mixture and exposure condition for a good mechanical property from Waste Glass Powder. The composition of mixing glass powder, cement, sand, and water to produce the optimum in concrete is with a variation of 5%:30%:65% because on this composition of concrete has a good durability and highest compressive strength. This is also supported by other studies conducted by Zeybek *et al.*, (2022) resulting that as much as 30% of cement is good for support by WGP.

WGP is good for use in making concrete because glass is a material that does not absorb water or zero water absorption. The nature of glass that does not absorb water can fill the cavities on concrete to the maximum. Glass in this case is a glass powder that has properties as a pozzolan that can increase the compressive strength of concrete. Glass contains no material which is dangerous, so that at the time of concrete work it is safe for humans.

CHAPTER IV EXPERIMENTAL METHOD

4.1 Introduction

The purpose of this experimental study is to investigate the mechanical properties of concrete containing glass powder with different proportions of glass powder. Calculate the compressive strength, tensile strength, and modulus elasticity of waste glass powder concrete by conducting some experimental mixtures of glass powder concrete. Specimens are produced at Pusat Inovasi Material Vulkanis Merapi UII and the strength of specimens is tested at Construction Material Laboratorium UII.

4.2 Materials

There are 5 materials used in this glass powder concrete mix, which are waste glass powder, cement, sand, gravel, and water, as follows. The methods of manufacturing waste glass powder concrete are mixing, molding, and drying.

4.2.1 Waste glass powder

Glass waste is collected from the Glass Waste Center, then we clean it, remove contaminants from it, and sort it according to color if possible. We grind it into small particles to obtain the required size of 75 microns. After that, the glass powder is dried to get rid of moisture.

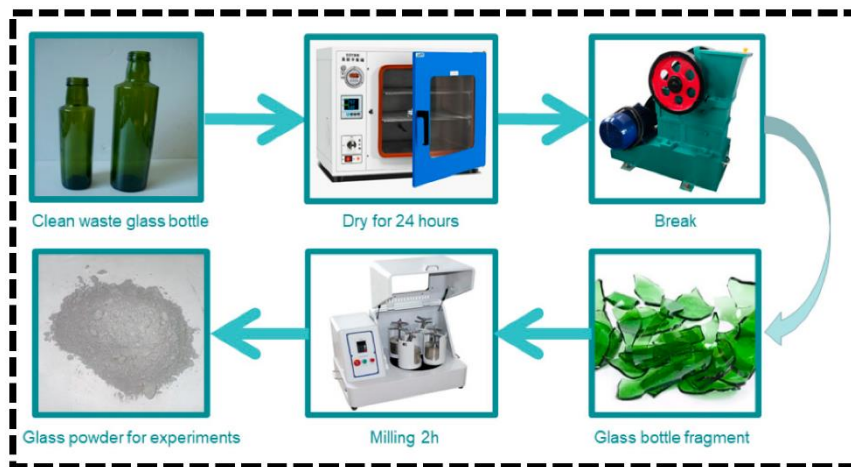


Figure 4.1 Preparation of waste glass powder

4.2.2 Cement

Ordinary Portland Cement (OPC) is used for this research with the brand “Semen Tiga Roda.”

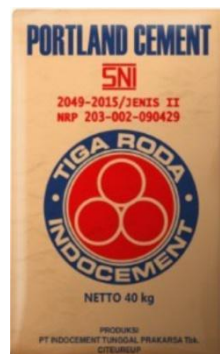


Figure 4.2 Semen Tiga Roda

The ratio of sand to cement was chosen because the results obtained by (Khalil et al., 2018) showed that the sand-binder ratio of 1.0 (out of the considered sand-binder ratios they considered) had the best mechanical properties, with economy also in view.

4.2.3 Gravel

The gravel is collected from the Dusun Cangkringan Sleman. Natural gravel with a maximum size of 20 mm passing through 16mm is used in this study retained as per IS:2386-1963 recommendation based on the study done by Vasudevan and Pillay.

4.2.4 Sand

The sand is collected from a sand quarry in Kangkringan, Sulaiman. To achieve a uniform sand particle size, the sand is sieved with a 4.75 mm sieve. Sand concrete and concrete containing glass powder were cast into cylinder molds with internal dimensions of 30cm x15 cm. Its bulk density was determined by dividing its mass, after removal from the mold, by its volume.

4.2.5 Water

Water is used in the chemical hydration reaction with cement. Well water from Pusat Inovasi Material Vulkanis Merapi UII is used. After the cylinders were completely submerged for 24 hours, water was wiped off the surfaces of the cylindrical samples. Each sample was then weighed. The mass of each cylindrical sample before treatment was subtracted from its mass after 24 hours of treatment in water to determine the mass of absorbed water. The water absorption ratio was determined by, considering the percentage, the ratio of the mass of absorbed water to the initial mass of sand concrete or concrete cylinder containing glass powder before curing in water.

4.3 Mix Design

The proportion of components of concrete containing glass is shown in Table 4.1. Sample quantity is limited to 5 pieces for the compressive strength test, and Elasticity Modulus test and 5 pieces for the tensile strength test.

Table 4.1 Describes The Mix Design For This Research.

No	Mix Proportions (%)			
	Ingredients	Proportion	Samples amount	
			30 cmx15 cm	
			Compressiv e and Modulus	Tensile
1	Cement:Sand:Gravel:Glas s powder	1:1.9:2.6:0%	5 Pieces	5 Pieces
2	Cement:Sand:Gravel:Glas s powder	1:1.9:2.6:10 %	5 Pieces	5 Pieces
3	Cement:Sand:Gravel:Glas s powder	1:1.9:2.6:15 %	5 Pieces	5 Pieces
4	Cement:Sand:Gravel:Glas s powder	1:1.9:2.6:20 %	5 Pieces	5 Pieces
5	Cement:Sand:Gravel:Glas s powder	1:1.9:2.6:25 %	5 Pieces	5 Pieces
6	Cement:Sand:Gravel:Glas s powder	1:1.9:2.6:30 %	5 Pieces	5 Pieces

The materials were collected by weight and mixed well to ensure even distribution of ingredients within the mixtures. The ratio is divided into 4.2 components: cement: sand: gravel, and glass powder according to weight ratios. The cylinders produced using both the mixing ratios of glass powder concrete and those of sand concrete were cured for 14 days, by immersion in water. The treatment period was limited to 14 days.

Materials are collected, proportions are calculated, and a concrete mixer is used to mix cement, sand, gravel, and glass powder. Gradually add water to a workable consistency, test for adjustment, and apply mixture evenly. Finish work as needed, follow curing procedures for strength, and monitor quality control. Commitment to the specific mix design for optimal concrete performance.

4.4 Sample Production and Strength Test

Glass powder ingredients (cement, sand, gravel, glass powder, and water) are mixed with concrete mixer. Sample production and their strength test are depicted in Figure 4.3, 4.4 and 4.5.



Figure 4.3 Compressive test (samples production and test)



Figure 4.4 Tensile Strength test



Figure 4.5 Elasticity Modulus Test

Regarding Figure 4.3, 4.4 and 4.5 the compression molding process is to place the mixture or slurry into the mold full. Next, compress it with a pressure of up to 20 MPa. Smooth and level the top face of the concrete using the appropriate tool or trowel. Shake the mold slightly, then pour the concrete onto the mold and place it to dry.

Drying Time – The drying time for concrete containing glass powder can vary depending on factors such as the specific composition of the concrete and environmental conditions. In the context of pouring glass powder into concrete in a kiln, the process involves burning the concrete at specific temperatures for a specific duration. For example, in a study on glass powder recycling, pouring glass powder in a furnace at 1120°C for 10 hours produced concrete components. However, the specific drying time for concrete containing glass powder is not explicitly mentioned in the sources provided. The compressive strength of both sand concrete and glass-containing concrete specimens was determined at curing ages of 14 days.

The tensile strength process involves testing the ability of a material to resist breaking under tension, or the pulling force. This is typically done by subjecting a sample to a controlled pulling force until it breaks, and then measuring the force applied at the point of fracture. In the context of concrete, tensile strength is an important property as it indicates the material's ability to withstand tension and stretching forces.

The elasticity modulus process involves measuring the stiffness or rigidity of a material, which is its ability to resist deformation under an applied force. This is typically done by subjecting a sample to a controlled stress or strain and measuring the resulting deformation. The elasticity modulus, also known as Young's modulus, is calculated as the ratio of stress to strain within the elastic limit of the material.

4.5 Research Flowchart

The flow of the research activities is presented in Figure 4.6.

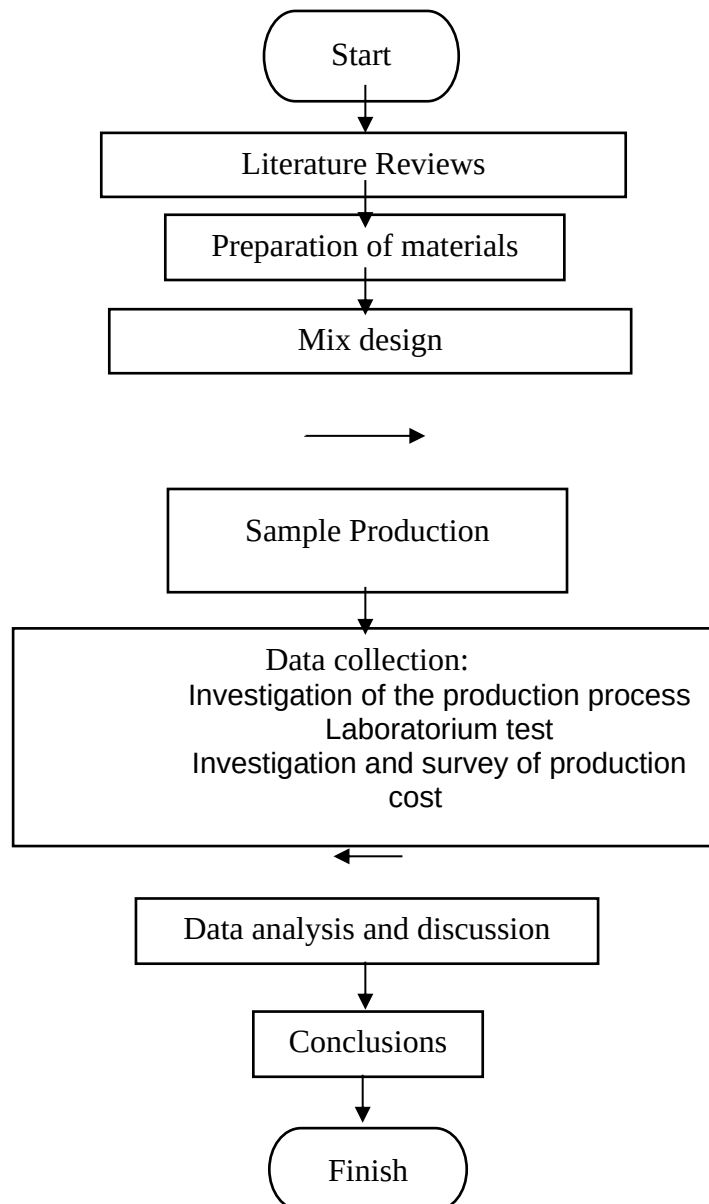


Figure 4.6 Research Flowchart

4.6 Research Schedule

Table 4.2 Research Schedule

Month		1				2				3				4			
Week		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Activities																	
1. Preparation	10	8	2														
2. Sample Production	24		24														
3. Laboratory Test and Survey																	
a. Compressive and Elasticity modulus tests	52						8	8	8	8	8	8	4				
b. Tensile test	52							8	8	8	8	8	8	4			
4. Data Analysis																	
a. Analysis of compressive strength and Modulus	12										4	4	4				
b. Analysis of Tensile strength	12										4	4	4				
5. Discussion																	
a. Mechanical characteristics	10													3	3	4	
b. Optimum waste glass powder	10													3	3	4	

CHAPTER V

RESULTS AND DISCUSSIONS

5.1 Aggregate Test

Aggregate is a natural mineral granule used as a mixture of concrete or mortar. In concrete 70% volume consists of aggregate. Depending on the large size of the grain, the aggregate is divided into two types, namely the fine aggregate and the coarse aggregate.

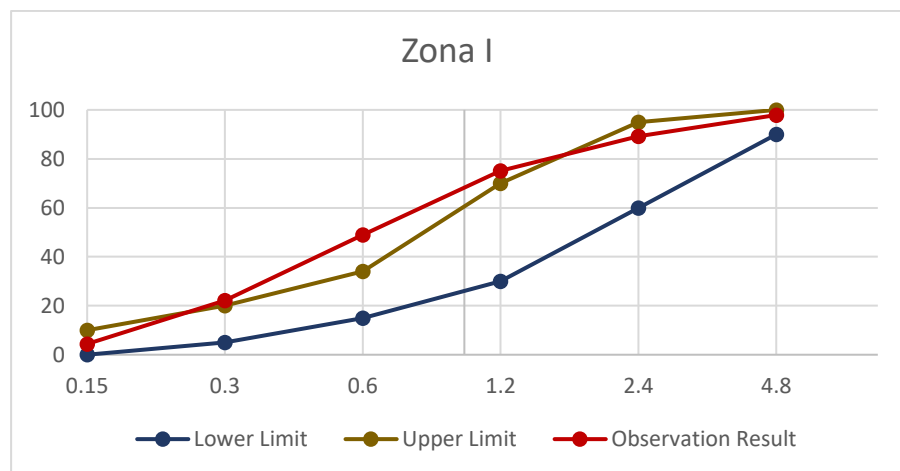
In this study, fine aggregates (grading according to Table 5.1) and coarse aggregate (grading according to Table 5.2) are used, and the relevant characteristics are reviewed in continuation. It should be noted that it is necessary to comply with the requirements of ASTM C33 to have high-quality concrete. Table 5.1.1 shows the fine aggregate and 5.1.2 shows the coarse aggregate.

5.1.1 Fine Aggregate

The terms of the fine aggregate are as follows: (a) It has a sharp and hard grain with a hardness index < 2.2 . (b) remain, not broken or destroyed by the influence of the weather. The sodium sulfate salt part is crushed maximum 12%, if with magnesium sulfate maximum 18%. (c) does not contain mud (fine-grained by 0.06 mm) more than 5%. (d) does not contain too much organic substance, which is evidenced by color experiments with a solution of NaOH 3%, i.e. fluid color above the fine aggregate deposits should not be darker than standard color/comparison. (e) fine Modulus of grain between 1.50 – 3.80 and with grain variation according to the gradation standard. (f) Specifically, for concrete with a high durability rate, the fine aggregate should be unreactive to alkali. (g) The fine aggregate of the sea or coast may be used provided that with instructions from the approved Material inspection Agency.

Table 5.1 Fine Aggregate Zones

Sieve Hole (mm)	Zone I		Zone II		Zone III		Zone IV	
	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit
4,8	90	100	90	100	90	100	95	100
2,4	60	95	75	100	85	100	95	100
1,2	30	70	55	90	75	100	90	100
0,6	15	34	35	59	60	79	80	100
0,3	5	20	8	30	12	40	15	50
0,15	0	10	0	10	0	10	0	15



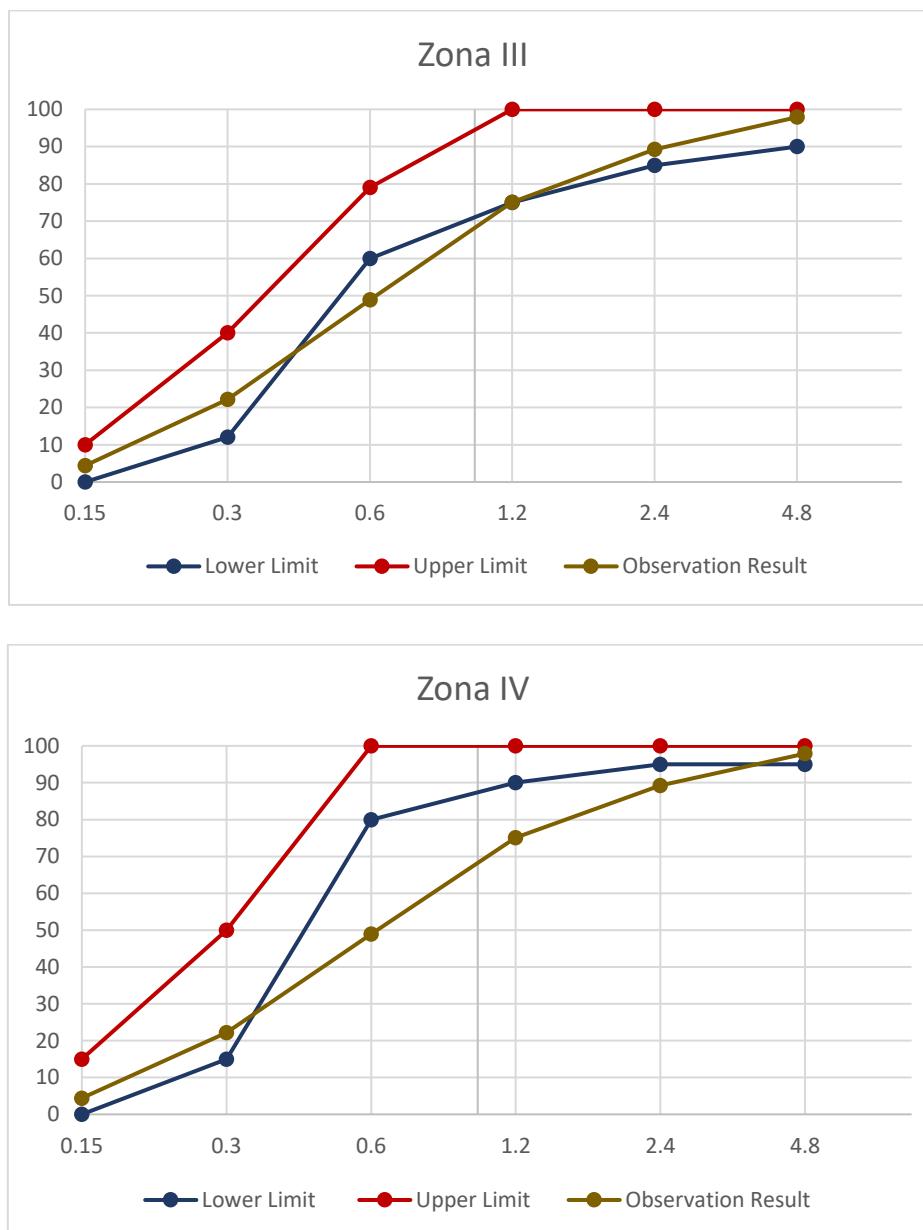


Figure 5.1 Fine Aggregate Zones

Table 5.2 Sieve Hole For Fine Aggregate

Sieve Hole (mm)	Cumulative Passing Weight		
	Upper Limit	Sample 1	Lower Limit
4,8	100	97,898	90
2,4	100	89,239	75
1,2	90	75,125	55
0,6	59	48,899	35
0,3	30	22,172	8
0,15	10	4,404	0

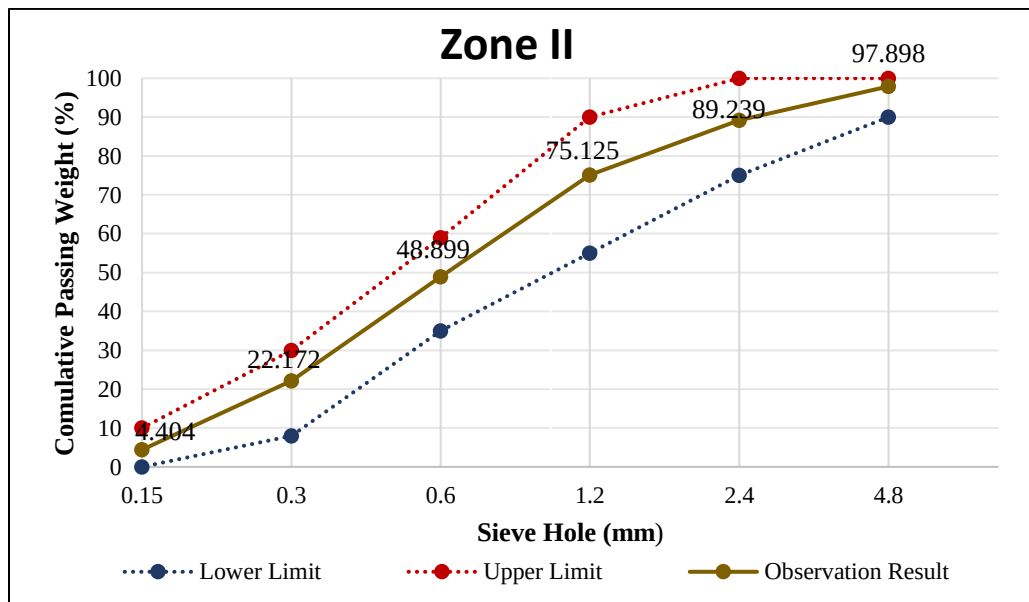


Figure 5.2 Sieve Hole of Fine Aggregate

Tests carried out are tests of water absorption, gravity test, sand clay, low density, and dense density in Appendix 1 and gradations for zone I, II, III, and IV. Based on Table 5.2 shows the gradations of fine aggregate and Table 5.2 shows the sieve hole.

5.1.2 Coarse Aggregate

The following coarse aggregate terms : (a) The imposition is loud and not porous. The hardness index is less than equal to 5% (tested with copper stem scratches). (b) remains or is not destroyed by the influence of the weather. If tested with a solution of sodium sulfate salt, the part is destroyed by a maximum of 12%, and if tested using magnesium sulfate, the part that is destroyed has a maximum of 18%. (c) does not contain mud more than 1% (fine-grained through 0.006 mm sieve). (d) Flat and oblong aggregate details should not be more than 20%. (e) The maximum grain size should not exceed 1/5 the smallest distance between the mold fields, the 1/3 thick concrete plate, 3/4 net distance between the reinforcement.

Table 5.3 Sieve Hole for Coarse Aggregate

Sieve Hole (mm)	40 mm		20 mm	
	low limit	up limit	low limit	up limit
40	95	100	100	100
20	30	70	95	100
10	10	35	25	55
4,8	0	5	0	10

Sieve Hole (mm)	Maximum Sieving	
	40 mm	20 mm
40	95-100	100
20	35-70	95-100
10	10-35	25-55
4,8	0-5	0-10

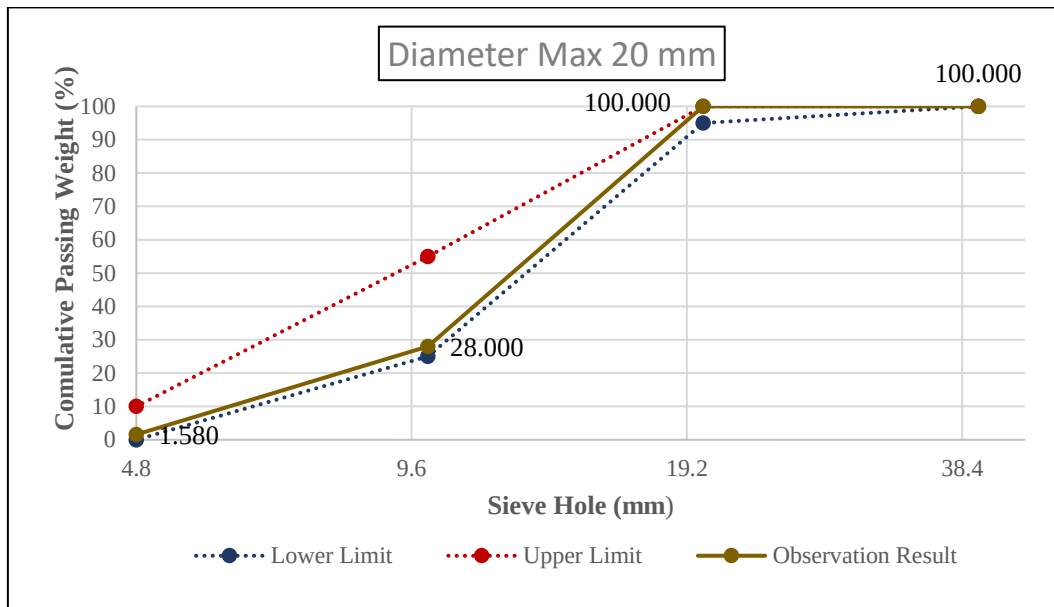


Figure 5.3 Sieve Hole of Coarse Aggregate

Tests carried out are tests of gravity test, sand clay, low density, and dense density, gravel clay content test in Appendix 1, and gradations. Based on Table 5.3 shows the gradations of fine aggregate and Table 5.3 shows the sieve hole.

5.2 Optimum Percentage Mix Design

The chemical composition of clear and colored glass powders are very similar and the materials could be declared as pozzolanic material as per ASTM standard. Being cleaner in nature, the flow of glass replaced mortar was found to be increased slightly with glass powder content. The optimum glass content is 20% and concrete compressive and tensile strength at 14 days. In this age the compressive strength was found slightly higher than the control concrete specimen. In the research that used the SikaCim concrete material that works to accelerate the hardening of concrete.

In addition, production of every six ton glass powder concrete results in the reduction of each ton CO₂ emission from cement production and save the environment significantly by reducing green-house gas and particulate production. Generally, the high surface area of milled waste glass changes the kinetics of chemical reaction toward beneficial pozzolanic reaction utilizing the available alkalis before production of a potential ASR gel. The mix compositions were tested to determine the compressive strength, tensile strength, and modulus elasticity. The exact compositions were chosen to create a variety of strengths.

A total of 10 samples concrete mixtures were produced, divided into different sizes of moulds such as cylinder concrete. The types of the mixture produced, which were the addition of samples concrete, thus the waste materials were added by volume in concrete. The form mix design using SNI-03-2834-2000 are shown in Table 5.4 below.

Table 5.4 Form Mix Design

Form Mix Design				
SNI-03-2834-2000				
No	Description	Results	Unit	Information
1	Required compressive strength of concrete (f'c)	20	MPa	be appointed
2	Standard deviation value (Sd)	-	MPa	
3	Margin (M)	12	MPa	
4	Average Compressive strength of concrete (f'cr)	32	MPa	(1)+(3)
5	Type of cement	Type 1		be appointed
6	Type of fine aggregate	alami		be appointed
	Type of coarse aggregate	Crushed Stone		be appointed
7	Free cement water factor	0,54		table 2 and figure 1 dan 2
	Maximum cement water factor value	0,6		
8	Cement water factor Used	0,54		
9	Slump	60-180	mm	be appointed
10	Maximum Aggregate size	20	mm	be appointed
11	Free water content	205		table 3
12	Cement Content	379,630	kg/m3	(11):(8)
13	Maximum cement content	-		
14	Minimum cement content	325		table 4
15	Cement grade used	379,630	kg/m3	
16	Cement water factor adjusted	-		

17	Large arrangement of fine aggregate grains	2		Gradation Zona	
18	Specific gravity of fine aggregate	2,581			
	Specific gravity of coarse aggregate	2,598			
19	% Fine aggregate	42,2	%	figure 13 / 14 / 15	
20	Specific gravity of the combined aggregate	2,591			
21	Concrete Weight	2327	kg/m3	figure 16	
22	Combined aggregate proportions	1742,370	kg/m3	(21)-(15)-(11)	
23	Proportion of fine aggregate	735,280	kg/m3	(19)*(22)	
24	proportion of coarse aggregate	1007,090	kg/m3	(22)-(23)	
No	Description	Cement (kg)	Water (kg)	Aggregate	
				Fine (kg)	Coarse (kg)
25	Theoretical mixture proportions (Aggregate SSD)				
	* Every m3	379,630	205,000	735,280	1007,090
	* Each test mixture (1 samples) : 0,02651 m3	20,126	10,868	38,980	53,390
26	Mix proportions with shrinkage figures (20%)				
	* Every m3	455,556	246,000	882,336	1208,508
	* Each test mixture (10 samples) : 0,05301 m3	24,151	13,042	46,777	64,068
	Ratio	1	0,5	1,9	2,6

Table 5.5 Mix Proportions

MIX PROPORTIONS									
Sampl e	Volume	Variation glass powder	Fine Agg	Coarse Agg	Cement	Water	Glass powder	Cement	SikaCim Concrete
(pcs)	(m3)	(%)	(kg)	(kg)	(kg)	(kg)	(Kg)	(Kg)	(ml)
10	0,05301	0	46,777	64,068	24,151	13,042	0,000	24,151	166,038
10	0,05301	10%	46,777	64,068	24,151	13,042	2,415	21,736	149,434
10	0,05301	15%	46,777	64,068	24,151	13,042	3,623	20,528	141,132
10	0,05301	20%	46,777	64,068	24,151	13,042	4,830	19,321	132,830
10	0,05301	25%	46,777	64,068	24,151	13,042	6,038	18,113	124,529
10	0,05301	30%	46,777	64,068	24,151	13,042	7,245	16,906	116,227
TOTAL			280,659	384,410	144,906	78,249	24,151	120,755	830,190

VOLUME					
m	1 cylinder	7 cylinder	8 cylinder	5 cylinder	10 cylinder
0,3	0,00530	0,03711	0,04241	0,02651	0,0530
0,15					

Based on Table 5.5 Mix Proportions shows that the mix design of the concrete. In the research that used the SikaCim concrete material that works to accelerate the hardening of concrete. According to Sharifi Y., Houshiar M. and Aghebati B. (2013), normally, the concrete strength was increased because of the maturity at the curing periods. In the arrangement of concrete, the cement deed as a glue which binds together the aggregates to attain the final cast product.

Waste Glass Powder can also be used as a binder with the partial replacement of cement, it also acts as a filler material. Waste glass when ground to a very fine powder shows pozzolanic properties as it contains high SiO_2 and therefore to some extent can replace cement in concrete and contribute strength development. In this study Glass Powder partially replaced at varying percentage 0 to 30 percent by weight of cement, and tested for its workability and Compressive strength up to 14 days of age and were compared with those of conventional concrete.

The overall test results shows that Waste Glass Powder could be utilized in concrete as a good substitute of cement. The research concluded that with the age of testing affects the compressive strength. The reduction of workability was observed with the increase of glass powder content, as the slump value decreased with a constant amount.

The utilisation of waste materials or mechanical by-items as a partial replacement for mixture in concrete is a feasible technique for lessening the utilisation of Ordinary Portland Cement (OPC), and therefore diminishing the natural and vitality effects of concrete creation. Waste glass powder used in concrete as a partial replacement of cement could be an important step toward the development of sustainable environmentally friendly, energy-efficient and economical infrastructure systems.

The waste glass powder offers sought concoction structure and reactivity for use as a supplementary cement material which can be a beneficial point to the substance of solidness, dampness resistance and sturdiness of cement. The glass powder could bring about the alkali-silica reaction (ASR) in cement, yet the glass powder could stifle their ASR propensity, an impact like supplementary cementitious materials (SCMs).

5.3 Production Process of the Samples

The glass powder production process of the samples starts with several activity which include prepare the raw material, sieve the sand, weight the material, mixing, pour the mixed material, and cure the fresh samples and. The documentation in the production process can be seen in Figure 5.4 – 5.8 with a detailed explanation of each manufacturing process as follows.

1. Prepare the raw material

In making glass powder, the first thing that needs to be prepared is the main materials which called as raw material. The main materials are waste glass powder, cement, gravel, sand, and water. Researchers obtained raw materials from building shops in Yogyakarta area.

2. Sieve the sand

Before mixing the raw material, it is necessary to sort the sand first.

3. Weight the material

Furthermore, researchers weighted the raw material according to the coefficient in Table 4.1 Mix Design of the proportion of 0%; 10%; 15%; 20%; 25%; 30% on each cement, sand, gravel, and glass powder.

4. Mixing

All raw materials are mixed using a mixer until all ingredients are well mixed according to Table 4.1 Mix Design of the proportion 1:1.9:2.6 and poured into cube molds with a size of 30 cm x 15 cm as much as 5 cubes for each proportion. The fine aggregate, cement, water and glass powder were added when mixer running. The concrete was placed in the moulds by using a concrete scoop and shovel.

5. Curing

Cure the fresh samples for 14 days to get maximum cubes results. In the research that used the SikaCim concrete material that works to accelerate the hardening of concrete.

6. Slump Test

Slump test is a way to find out, as well as determine the consistency or quality level of the concrete mixture. The slump test is done by filling the mold up about 1/3 full, rod it 25 times, fill it up to 2/3 full, rod it 25 more times, and then finally fill it to the top and rod it again. Then remove the mold and measure the slump from the top down. The slump test using 6 variation which explained on Table 5.6 below.

Table 5.6 Slump Test

NO.	Variation	slump test(mm)
1	0%	160
2	10%	111
3	15%	140
4	20%	150
5	25%	100
6	30%	170



Figure 5.4 Mixing The Raw Materials and Slump Test



Figure 5.5 Samples In The Water



Figure 5.6 Raw Material



Figure 5.7 Samples After Curing



Figure 5.8 Samples in The Cylinder

5.4 Mechanical Characteristics

An experimental method has been carried out to investigate the mechanical properties of glass powder with 6 variations of glass powder: 0%; 10%; 15%; 20%; 25%; and 30% of glass powder.

5.4.1 Compressive Strength Test

The compressive quality of concrete shapes would deliver the information of the concrete potential strength mixture from which it was tested. The compressive strength of concrete was carried out according to ASTM C109. A compressive strength machine (Standard Pengoprasian Alat Compressive Test Machine Controls (CAT C75) and Standard Pengoprasian Alat Compressive Test Machine (ELE INTERNATIONAL ADR 3000) was used to determine the compressive strength of the concrete (capacity of 1000 KN) cubes cured for 14 days.

The compressive strength test was taken from six samples which shown on Appendix 1. Here is the glass powder sample after the compression test shown on Figure 5.9.



Figure 5.9 Compression Test Process

Table 5.7 Specimen Dimension 0% Glass Powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Diameter	150	150	150	mm
Hight	298	300	310	mm
Wight Of Specimen	12,70	12,60	12,80	kg

Cross-Sectional Area	17671,46	17671,46	17671,46	mm ²
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Table 5.8 Specimen Dimension 10% Glass Powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Diameter	150	150	150	mm
Hight	299	310	300	mm
Wight Of Specimen	12,53	12,63	12,67	kg
Cross-Sectional Area	17671,46	17671,46	17671,46	mm ²

Table 5.9 Specimen Dimension 15% Glass Powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Diameter	150	150	150	mm
Hight	330	330	320	mm
Wight Of Specimen	12,71	12,66	12,58	kg
Cross-Sectional Area	17671,46	17671,46	17671,46	mm ²

Table 5.10 Specimen Dimension 20% Glass Powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Diameter	150	150	150	mm
Hight	299	300	330	mm
Wight Of Specimen	12,68	12,67	12,59	kg
Cross-Sectional Area	17671,46	17671,46	17671,46	mm ²

Table 5.11 Specimen Dimension 25% Glass Powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Diameter	150	150	150	mm
Hight	300	300	320	mm
Wight Of Specimen	12,28	12,12	12,27	kg
Cross-Sectional Area	17671,46	17671,46	17671,46	mm ²

Table 5.12 Specimen Dimension 25% Glass Powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Diameter	150	150	150	mm
Hight	300	300	299	mm
Wight Of Specimen	12,35	12,33	12,24	kg
Cross-Sectional Area	17671,46	17671,46	17671,46	mm ²

Table 5.13 Compressive Strength

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit	Compressive Test Average (Mpa)
0% GP					
Maximum Load	380.67	372.9	494.12	Kn	23.53
Duration	36	39	46	Seconds	
Compressive Test	21.54	21.10	27.96	Mpa	
10% GP					
Maximum Load	347.5	477.68	397.99	kn	23.07
Duration	44	45	39	Seconds	
Compressive Test	19.66	27.03	22.52	Mpa	
15% GP					
Maximum Load	451.36	420.44	518.12	kn	26.21
Duration	39	40	51	Seconds	
Compressive Test	25.24	23.79	29.32	Mpa	
20% GP					
Maximum Load	569.7	611.99	426.74	kn	30.34
Duration	54	58	42	Seconds	
Compressive Test	32.24	34.63	24.15	Mpa	
25% GP					
Maximum Load	407.97	451.02	439.12	kn	24.49
Duration	39	43	42	Seconds	
Compressive Test	23.09	25.52	24.85	Mpa	

30% GP					
Maximum Load	402.36	445.36	444.89	kn	24.38
Duration	39	43	42	Seconds	
Compressive Test	22.77	25.20	25.18	Mpa	

The measured compressive strengths value with various content of glass powder for 28th days is given in Table 5.6- Table 5.12. The compressive strength for the initial test was taken from three samples and then averaged. It shows that the compressive strength for each material proportion are 23,53 Mpa, 23.07 Mpa, 26.22 Mpa, 30,33 Mpa, 24,28 Mpa, and 24,38 Mpa. However, the trend of all compressive result clearly shown the tendency of the small decrease in the strength in the concretes containing higher utilization of the glass powder. The Figure 5.10 shows how the glass powder behaved when compressed under load and the graph shows the average compressive strength of the given samples.

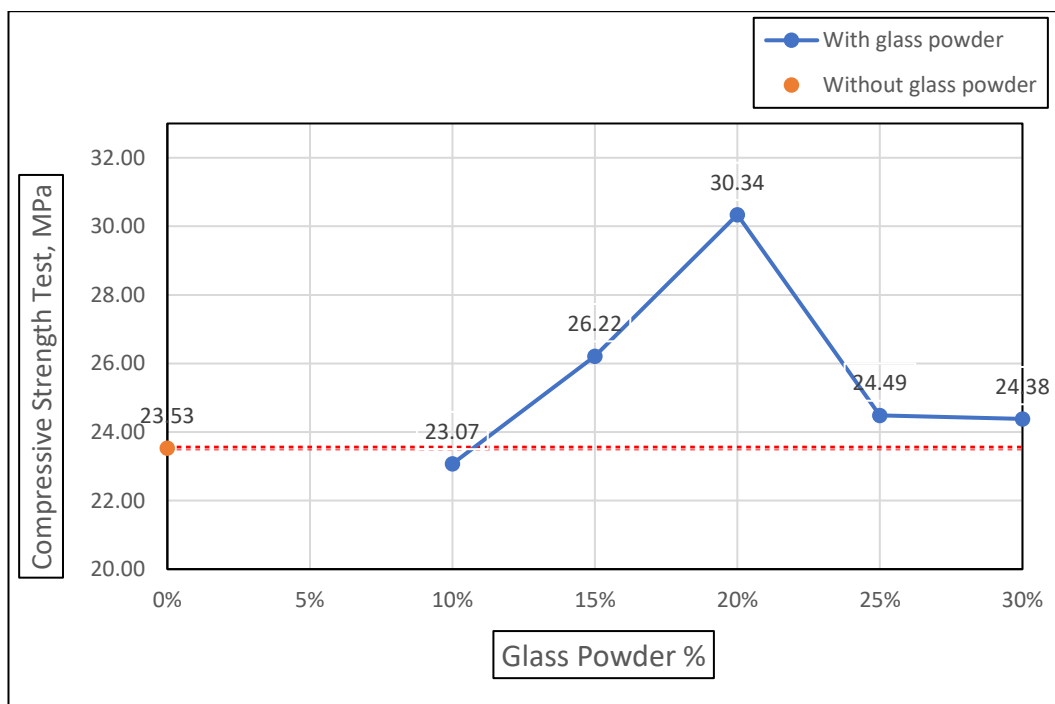


Figure 5.10 Variations of Compressive Test with % glass powder content

Based on Figure 5.10 shows that there is a difference in the compressive strength value of each mix proportion. At 20% glass powder has the highest compressive strength value followed by 10% glass powder. While the lowest compressive strength value is at 0% glass powder. It was observed that the concretes with 10% and 30% of glass powder had shown a reduction of compressive strength. The compressive strength of concrete was carried out according to ASTM C109. Pozzolanic materials in Water Glass Powder increased the compressive strength smoothly on 14 days, glass powder can be used as cement replacement until 15%, which can be considered as a reasonable amount in producing sustainable concrete (Muhedin, 2023). The compressive strength of cube concrete shapes would give the data of the concrete potential strength mixture from which it was tested. According to Sharifi Y., Houshiar M. and Aghebati B. (2013), normally, the concrete strength was increased because of the maturity at the curing periods. In the arrangement of concrete, the cement deed as a glue which binds together the aggregates to attain the final cast product. Waste Glass Powder can also be used as a binder with the partial replacement of cement, it also acts as a filler material. Waste glass when ground to a very fine powder shows pozzolanic properties as it contains high SiO_2 and therefore to some extent can replace cement in concrete and contribute strength development.

Concrete has exceptional strength when it comes to compression. It possesses high compressive strength due to the strong bond between the cementitious paste and the aggregate particles. When a force is applied to concrete in compression, it can withstand tremendous pressure before it starts to crack or fail. In this research Pozzolanic materials in Water Glass Powder increased the compressive strength smoothly on 14 days. It was found that compressive strength and water absorption increased with an increase in the percentage of glass powder on 20%. Miranda et al (2014), concluded that an increase of compressive strength could be achieved when 20% cement was replaced by glass powder and the next percentage would be depend on the water absorption, the use of glass powder as a partial cement replacement with a substitution level of 0–20%.

On the other hand, powder content increases and an improvement of compressive strength at the early age followed by a decrease with the age of curing due to the Alkali-Silica Reaction on the percentage 25% and 30%. The other research from Rahma et al (2017) shows, that concrete with cement replaced by 15% and 20% glass powder exhibited the highest strength increase and correspondingly the lowest porosity. Beyond a replacement of 20%, calcium hydroxide became insufficient for the pozzolanic reaction of glass powder. The results showed that the average compressive strength of concrete decreased with an increase in temperature indicated by a 10% to 15% decrease.

5.4.2 Tensile Strength Test

Split Tensile of concrete was tested in compression, according to ASTM C109 to determine the compressive strength and split tensile strength, respectively. Naamadadin et al, (2020) tentatively explored the impact of supplanting 4%, 8%, and 12% of cement with WGP having molecule sizes extending from 3 μm to 60 μm on compressive and tensile quality. Here is the glass powder sample after the compression test shown on Table 5.13 – 5.19.



Figure 5.11 Tensile Test Process

Table 5.14 Specimen Dimension 0% Glass Powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Diameter	150	150	150	150	150	mm
Hight	300	300	300	300	300	mm
Wight Of Specimen	12,7	12,9	12,8	12,7	12,9	kg

Table 5.15 Specimen Dimension 10% Glass Powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Diameter	150	150	150	150	150	mm
Hight	320	310	299	299	300	mm
Wight Of Specimen	12,7	12,7	12,6	12,4	12,4	kg

Table 5.16 Specimen Dimension 15% Glass Powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Diameter	150	150	150	150	150	mm
Hight	330	330	300	300	320	mm
Wight Of Specimen	12,666	12,683	12,583	12,615	12,675	kg

Table 5.17 Specimen Dimension 20% Glass Powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Diameter	150	150	150	150	150	mm
Hight	330	299	300	320	300	mm
Wight Of Specimen	12,709	12,561	12,182	12,737	12,47	kg

Table 5.18 Specimen Dimension 25% Glass Powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Diameter	150	150	150	150	150	mm
Hight	310	330	300	300	320	mm
Wight Of Specimen	12,281	12,364	12,23	12,063	12,401	kg

Table 5.19 Specimen Dimension 30% Glass Powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Diameter	150	150	150	150	150	mm
Hight	300	300	300	300	330	mm
Wight Of Specimen	12,127	12,525	12,5	12,467	12,357	kg

Table 5.20 Tensile Strength

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit	Average of Tensile Strength (Mpa)
0% Glass Powder							
Maximum Load	111	110	99	104	93	KN	1.46
Tensile Strength	1,570	1,556	1,401	1,471	1,316	Mpa	
10% Glass Powder							
Maximum Load	96	119	100	100	115	KN	1.47
Tensile Strength	1,300	1,629	1,419	1,419	1,627	Mpa	
15% Glass Powder							
Maximum Load	130	105	125	91	104	KN	1.49
Tensile Strength	1,58	1,35	1,76	1,28	1,36	Mpa	
20% Glass Powder							
Maximum Load	122	102	115	108	116	KN	1.54
Tensile Strength	1,56	1,35	1,76	1,28	1,36	Mpa	
25% Glass Powder							
Maximum Load	106	124	112	90	120	KN	1.49
Tensile Strength	1,45	1,59	1,58	1,27	1,53	Mpa	
30% Glass Powder							
Maximum Load	120	98	115	93	98	KN	1.43

Tensile Strength	1,69	1,38	1,62	1,38	1,28	Mpa	
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The measured tensile strength value with various content of glass powder for 14th days is given in Table 5.19. The tensile shows that tensile strength for each material proportion are 1.46 Mpa, 1.47 Mpa, 1.49 Mpa, 1.54 Mpa, 1.49 Mpa, 1.43 Mpa. The Figure 5.12 shows how the glass powder behaved and the graph shows the average tensile strength of the given samples.

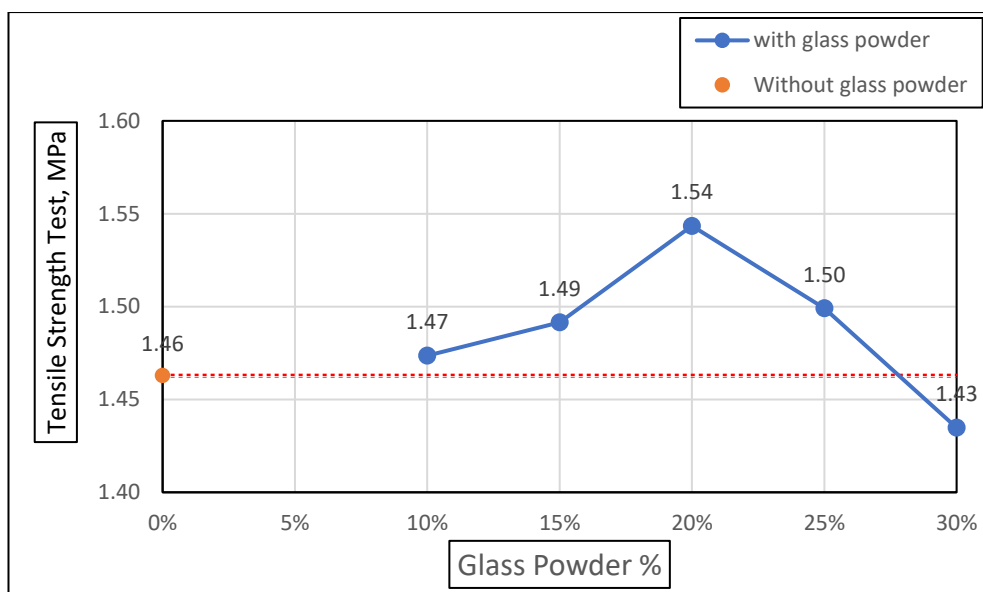


Figure 5.12 Variations of Tensile Strength Test with % glass powder content

Based on Figure 5.12 shows that there is a difference in the tensile strength value of each mix proportions. At 0% glass powder has the lowest tensile strength value followed by 15% glass powder. While the highest tensile strength value is at 20% glass powder. The tensile strength increases progressively with addition of 10% to 20%. The results also indicate that the incorporation of glass powder had improved the stiffness of the composite. As a result, the concrete will turn up to failure at the apparent tensile stress other than the rigidity. Therefore, in designing these structures, tensile strength is a major element and crucial than compressive strength.

Glass is the result of crystallization of inorganic compounds that unravel. Glass powder has its advantages and can be a material of concrete, one of which is glass powder. Glass powder has some advantages over other pore fillers, namely: (1) Zero water absorption (2) The hard glass properties make the concrete resistant to abrasion that can only be achieved by a little natural aggregate, (3) glass powder Improve the element of the fresh concrete to increase strength without the use of Superplasticizer.

As refer to Vishaliny H et.al (2013), they have used 10% augmentation of glass powder utilisation with concrete G30 but they used 28 and 60 days of curing. In every samples case, when the percentage of glass powder increased, the crack form quickly in areas affected by load. The shrinkage condition against concrete and affects the strength of materials. This reduction is related to the variations of the water content of the mortar, which leads to the development of tensile stresses at the concrete.

Naaamandadin et al (2020), shows that using glass powder with particle size $< 75 \mu\text{m}$ can exhibit pozzolanic characteristics inhibiting the ASR gel formation, improving the strength performance, tensile strengths of concrete increase initially as the replacement percentage of cement by glass powder increases become maximum at about 20%. The use of 20 % glass powder as cement replacement achieved better tensile strength. There is a strong increase in drag because of the Pozzolan glass waste powder is a material containing silica and alumina on the 20%, the compound will react chemically with calcium hydroxide at room temperature and form compounds that have properties like cement. The results showed that the average tensile strength of concrete decreased with an increase in temperature indicated by a 10% and 30% decrease.

On a variation of glass waste powder 25% and 30%, the tensile strength of concrete decreased. This is due to an increase in aggregates and variation of glass powder and can be affected by temperature. There is a strong decline in the withdrawal due to too much powder waste glass of cement percentage decreased much, so that the connective power between aggregates decreases. This is due to

glass waste powder being a pozzolan material that contains silica and alumina, but has no binding properties such as cement.

5.4.3 Modulus Of Elasticity

The modulus of elasticity was measured in accordance with ASTM C469. Patel et al., (2020) inspected the affect of up to 20% WGP utilize with two closely particulate sizes (75 μ m and 63 μ m) on a few concrete qualities such as compressive, tensile, modulus elasticity. Here is in Figure 5.13 the Modulus Elasticity Test.



Figure 5.13 Modulus Elasticity

Table 5.21 Specimen Dimension 0% Glass Powder

Description	Cylinder 1	Cylinder 2	Unit
Diameter	150	150	mm
Hight	300	300	mm
Wight Of Specimen	12,56	12,75	kg
Cross-Sectional Area	17671,46	17671,46	mm ²

Table 5.22 Specimen Dimension 10% Glass Powder

Description	Cylinder 1	Cylinder 2	Unit
Diameter	150	150	mm
Hight	299	300	mm
Wight Of Specimen	12,45	12,68	kg
Cross-Sectional Area	17671,46	17671,46	mm ²

Table 5.23 Specimen Dimension 15% Glass Powder

Description	Cylinder 1	Cylinder 2	Unit
Diameter	150	150	mm
Hight	300	330	mm
Wight Of Specimen	12,70	12,65	kg
Cross-Sectional Area	17671,46	17671,46	mm ²

Table 5.24 Specimen Dimension 20% Glass Powder

Description	Cylinder 1	Cylinder 2	Unit
Diameter	150	150	mm
Hight	300	300	mm
Wight Of Specimen	12,37	12,71	kg
Cross-Sectional Area	17671,46	17671,46	mm ²

Table 5.25 Specimen Dimension 25% Glass Powder

Description	Cylinder 1	Cylinder 2	Unit
Diameter	150	150	mm
Hight	300	310	mm
Wight Of Specimen	12,15	12,17	kg
Cross-Sectional Area	17671,46	17671,46	mm ²

Table 5.26 Specimen Dimension 25% Glass Powder

Description	Cylinder 1	Cylinder 2	Unit
Diameter	150	150	mm
Hight	300	300	mm
Wight Of Specimen	12,54	12,22	kg
Cross-Sectional Area	17671,46	17671,46	mm ²

Table 5.27 Modulus of Elasticity

Description	Cylinder 1	Cylinder 2	Unit	Average of Modulus Elasticity (Mpa)
0% Glass Powder				
Maximum Load	479,4	491,8	KN	27,48
Duration	489	337	Second	
Modulus Test	27,13	27,83	Mpa	
10% Glass Powder				
Maximum Load	340,6	436,3	KN	21,98
Duration	242	309	Second	
Modulus Test	19,27	24,69	Mpa	
15% Glass Powder				
Maximum Load	428,2	561,6	KN	28,01
Duration	211	158	Second	
Modulus Test	24,23	31,78	Mpa	
20% Glass Powder				
Maximum Load	559,3	607,6	KN	33,02
Duration	162	136	Second	
Modulus Test	31,65	34,38	Mpa	

25% Glass Powder				
Maximum Load	459,6	460,6	KN	26,04
Duration	159	86	Second	
Modulus Test	26,01	26,06	Mpa	
30% Glass Powder				
Maximum Load	354,6	392,1	KN	21,13
Duration	133	138	Second	
Modulus Test	20,07	22,19	Mpa	

The measured modulus elasticity value with various content of glass powder for 28th days is given in Table 5.20 - Table 5.26. It shows that the modulus elasticity for each material proportions are 27,48 Mpa, 21,98 Mpa, 28,01 Mpa, 33,02 Mpa, 26,04 Mpa, and 21,13 Mpa. The Figure 5.14 shows how the average of modulus elasticity of the given samples.

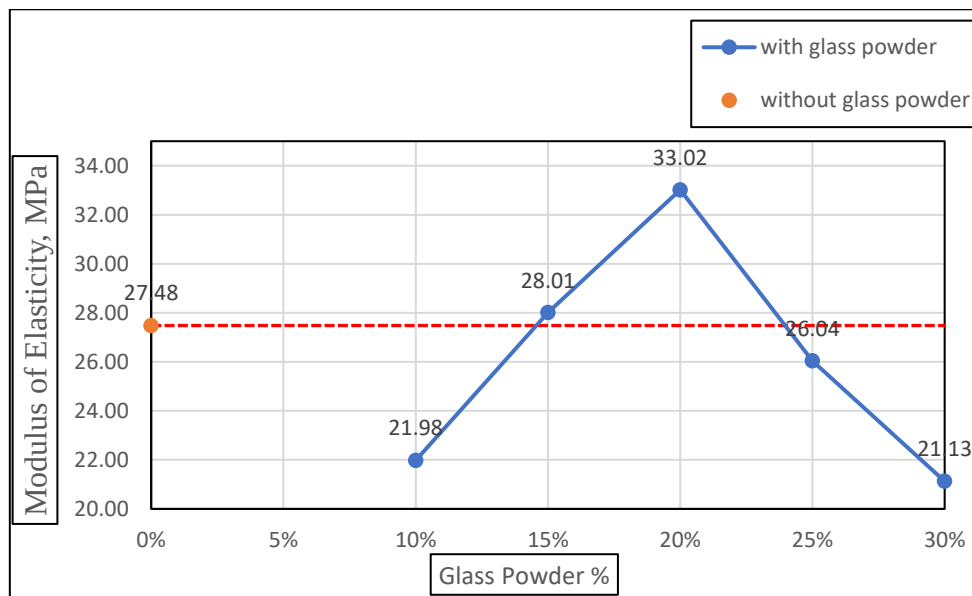


Figure 5.14 Variations of Elasticity modulus
with % glass powder content

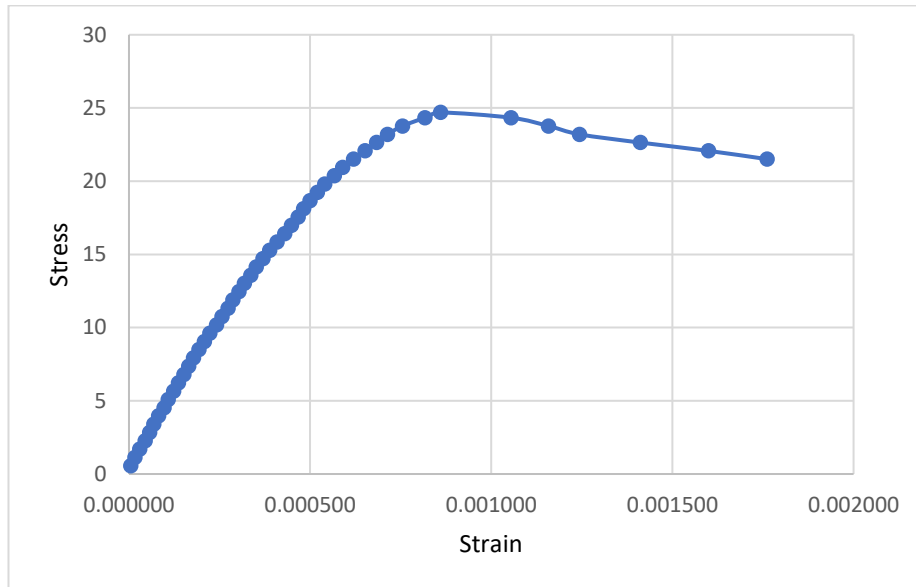


Figure 5.15 Relationship Between Stress and Strain

Based on Figure 5.14 shows that there is a difference in the modulus elasticity value of each mix proportions. At 20% glass powder has the highest modulus elasticity due to the highest compressive strength followed by 15% glass powder. Using glass powder with particle size $< 75 \mu\text{m}$ can exhibit pozzolanic characteristics inhibiting the ASR gel formation, improving the modulus elasticity and strength performance. Modulus elasticity containing glass powder were consistent with design guidelines and can be reliably predicted from compressive strength. It has been demonstrated that when the volume fraction of glass powder increased, the values of the elastic modulus, impact strength, and hardness increased as well.

While the lowest modulus elasticity value is at 30% glass powder. It was observed that the concretes with 10% and 30% of glass powder had shown a reduction of modulus elasticity. Based on Figure 5.15 shows that the relationship between strain and stress with 10% glass powder. The lower modulus of elasticity for concrete at higher glass substitution level is credited to the overpowering impact of weakening figure as compared to the advantageous impacts given by the pozzolanic response of glass powder. Elasticity modulus decreases with the rise of

glass powder content, whereas the elasticity modulus sharply increases as its content. In expansion, the type of hydration products formed during the pozzolanic reaction could also result in an overall lower elastic modulus. Whatever the GP particles' size, the compressive strength, compression toughness, and elastic modulus of low w/b ratio concrete specimens are relatively higher than those of the high w/ b ratio.

5.4.4 Slump Test

Slump test is a way to find out, as well as determine the consistency or quality level of the concrete mixture. Practically, the main function of the slump test is to measure the workability of the concrete that has been made and will be used. The measurement of the slump must be done immediately by measuring the perpendicular between the top edge of the mold and the average height of the test object. In this study the Slump test is explained by Table 5.6 and Figure 5.16 with 6 variations of 0%, 10%, 15%, 20%, 25%, 30%.

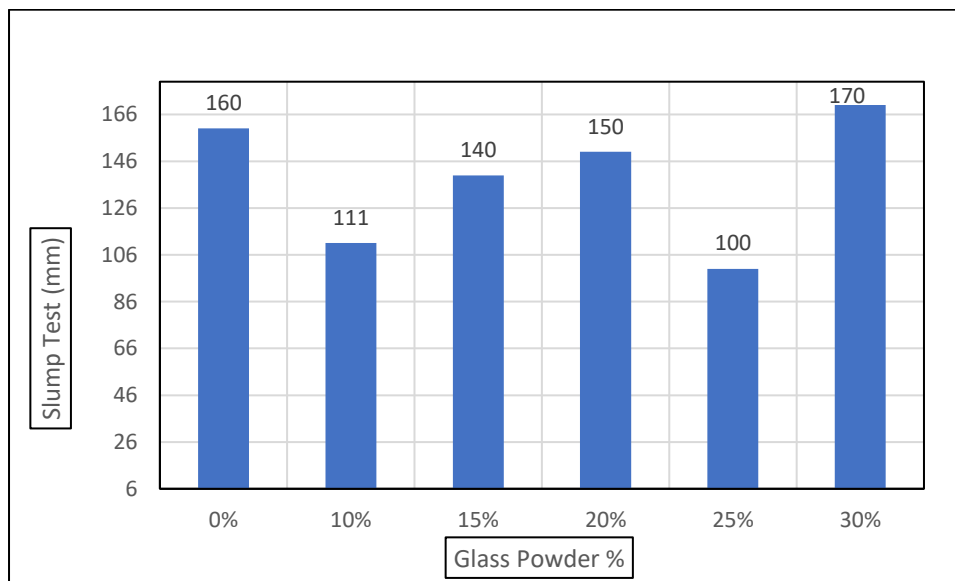


Figure 5.16 Slump Test Process

Based on the calculations it is known that the concrete slump value shows that the concrete has enough consistency to be cast and to fill the gaps and cavities well. The 30% variation has the maximum value and the lowest value is in the 10%

variation. The high and low value of the slump is affected by the aggregate grain and the quantity of water during the study.

CHAPTER VI CONCLUSION

6.1 Conclusion

Based on the results of the discussion of this study, the following conclusions are obtained.

1. The effect of Glass Powder (GP) can improve the mechanical properties of concrete by the means of pozzolanic activity. The test results showed that the compressive strength, tensile strength, and modulus elasticity (MOE) decreased with the increase of GP Content. They have been tested for its compressive strength and split tensile up to 14 days of curing. It was expected to undergo pozzolanic reactions with cement hydrates, forming secondary Calcium Silicate Hydrate (C-S-H) once waste glass was milled down to the micro size particles. The results indicate that the concrete with waste glass powder was able to increase the modulus elasticity of concrete and also the compressive strength.
2. The optimum percentage of glass powder is 20% that maximizes the mechanical properties and durability of concrete without compromising its workability. There is a strong increase because of the pozzolan glass waste powder is a material containing silica and alumina, the compound will react chemically with calcium hydroxide at room temperature and form compounds that have properties like cement. The results showed that the compressive strength, tensile strength, and modulus of elasticity of glass powder concrete at 14 days of testing which can be classified achieving the objective because higher than conventional concrete.

6.2 Suggestion

Generally, the high surface area of milled waste glass powder changes the kinetics of chemical reaction toward beneficial pozzolanic reaction utilizing the available alkalis before production of a potential alkali silica response or ASR gel. However, further research on durability and ASR aspects of glass replaced concrete is required to suggest this material for sustainable concrete practice. Furthermore, environmental effects can be minimised and the use of cement can be minimized through this research.

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APPENDIX

Appendix 1. Fine Aggregate

EXAMINATION OF SPECIFIC GRAVITY AND WATER ABSORPTION

Description	Observation Result	Unit
Absolute dry weight of sand, grams (Bk)	495.5	gram
Saturated surface dry (SSD) weight of sand, grams	500	gram
Weight of pycnometer containing sand and water, grams (Bt)	1004	gram
Weight of pycnometer filled with water, grams (B)	696	gram
Bulk specific gravity, $(Bk/(B+500-Bt))$	2.581	
Surface dry saturated specific gravity, $(500/(B+500-Bt))$	2.604	
Apparent specific gravity, $(Bk/(B+Bk-Bt))$	2.643	
Water absorption, $((500-Bk)/(Bk \times 100\%))$	0.908	%

SAND CLAY CONTAINMENT TEST

Description	Observation Result	Unit
Dry aggregate weight (W1), grams	500	gram
Oven-dry aggregate weight after washed (W2), grams	491	gram
No.200 sieve passing weight	1.8	%

LOOSE DENSITY

Description	Observation Result	
Cylinder diameter	15	cm
Cylinder height	30	cm
Cylinder weight	8896	gram
Cylinders + oven-dry aggregate weight (W2)	15738	gram
Aggregate weight (W3)	6842	gram
Cylinders volume (V)	5301.43 8	cm ³
Loose Density, (W3/V)	1.291	gram/cm ³

DENSE DENSITY

Description	Observation Result	
Cylinder diameter	15	cm
Cylinder height	30	cm
Cylinder weight	8896	gram
Cylinders + oven-dry aggregate weight (W2)	17516	gram
Aggregate weight (W3)	8620	gram
Cylinders volume (V)	5301.43 8	cm ³
Dense Density, (W3/V)	1.626	gram/cm ³

SIEVE ANALYSIS TEST

Sieve Hole (mm)	Retained Weight (gr)	Retained Weight (%)	Comulative Retained Weight (%)	Comulative Passing Weight (%)
40		0.000	0.000	100.000
20		0.000	0.000	100.000
10		0.000	0.000	100.000
4.8	42	2.102	2.102	97.898
2.4	173	8.659	10.761	89.239
1.2	282	14.114	24.875	75.125
0.6	524	26.226	51.101	48.899
0.3	534	26.727	77.828	22.172
0.15	355	17.768	95.596	4.404
Remaints	88	4.404		
Sumation	1998	100.000	262.262	

Fineness
Modulus

2.623

Sieve Hole (mm)	Percent of Aggregate Grains that Pass the Sieve			
	Zona I	Zona II	Zona III	Zona IV
10	100	100	100	100
4,8	90-100	90-100	90-100	95-100
2,4	60-95	75-100	85-100	95-100
1,2	30-70	55-90	75-100	90-100
0,6	15-34	35-59	60-79	80-100
0,3	5-20	8-30	12-40	15-50
0,15	0-10	0-10	0-10	0-15

Sieve Hole (mm)	Comulative Passing Weight		
	Upper Limit	Sample 1	Lower Limit
4.8	100	97.898	90
2.4	100	89.239	75
1.2	90	75.125	55
0.6	59	48.899	35
0.3	30	22.172	8
0.15	10	4.404	0

Sieve Hole (mm)	Zona I		Zona II		Zona III		Zona IV	
	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit
4.8	90	100	90	100	90	100	95	100
2.4	60	95	75	100	85	100	95	100
1.2	30	70	55	90	75	100	90	100
0.6	15	34	35	59	60	79	80	100
0.3	5	20	8	30	12	40	15	50
0.15	0	10	0	10	0	10	0	15

Appendix 2. Coarse Aggregate

EXAMINATION OF SPECIFIC GRAVITY AND WATER ABSORPTION

Description	Observation Result	Unit
Absolute dry gravel weight, grams (Bk)	4873	gram
Weight of gravel in saturated dry face condition (SSD), grams (Bj)	5000	gram
Weight of gravel in water, grams (Ba)	3124.5	gram
Bulk specific gravity ($Bk/(Bj-Ba)$)	2.598	
Specific weight of face dry ($Bj/(Bj-Ba)$)	2.666	
Apparent specific gravity ($Bk/(Bk-Ba)$)	2.787	
Water absorption ($(Bj-Bk)/(Bk \times 100\%)$)	2.606	%

LOOSE DENSITY

Description	Observation Result	
Cylinder diameter	15	cm
Cylinder height	30	cm
Cylinder weight	8896	gram
Cylinders + oven-dry aggregate weight (W2)	16586	gram
Aggregate weight (W3)	7690	gram
Cylinders volume (V)	5301.43 8	cm ³
Loose Density, (W3/V)	1.451	gram/cm ³

DENSE DENSITY

Description	Observation Result	
Cylinder diameter	15	cm
Cylinder height	30	cm
Cylinder weight	8896	gram
Cylinders + oven-dry aggregate weight (W2)	17347	gram
Aggregate weight (W3)	8451	gram
Cylinders volume (V)	5301.43 8	cm ³
Dense Density, (W3/V)	1.594	gram/cm ³

GRAVEL CLAY CONTENT TEST

Description	Observation Result	Unit
Dry aggregate weight (W1), grams	2000	gram
Oven-dry aggregate weight after washed (W2), grams	1986	gram
No.200 sieve passing weight	0.7	%

SIEVE ANALYSIS TEST

Sieve Hole (mm)	Retained weight (gram)	Retained weight (%)	Comulative Retained Weight (%)	Comulative Passing Weight (%)
40		0.000	0.000	100.000
20		0.000	0.000	100.000
10	3600	72.000	72.000	28.000
4.8	1321	26.420	98.420	1.580
2.4	35	0.700	99.120	0.880
1.2	16	0.320	99.440	0.560
0.6	0	0.000	99.440	0.560
0.3	0	0.000	99.440	0.560
0.15	0	0.000	99.440	0.560
Remaints	28	0.560		
Sumation	5000	100.000	667.300	

Fineness Modulus

6.673

Sieve Hole (mm)	Persen Butiran Agregat yang Lolos Ayakan/Besar Butiran Maksimum	
	40 mm	20 mm
40	95-100	100
20	35-70	95-100
10	10-35	25-55
4,8	0-5	0-10

Sieve Hole (mm)	40 mm		20 mm	
	low limit	up limit	low limit	up limit
40	95	100	100	100
20	30	70	95	100
10	10	35	25	55
4.8	0	5	0	10

Appendix 3. Mix Design

Form Mix Design				
SNI-03-2834-2000				
No	Description	Results	Unit	Information
1	Required compressive strength of concrete (f'c)	20	MPa	be appointed
2	Standard deviation value (Sd)	-	MPa	
3	Margin (M)	12	MPa	
4	Average Compressive strength of concrete (f'cr)	32	MPa	(1)+(3)
5	Type of cement	Type 1		be appointed
6	Type of fine aggregate	Natural		be appointed
	Type of coarse aggregate	Crushed Stone		be appointed
7	Free cement water factor	0.54		table 2 and figure 1 dan 2
	Maximum cement water factor value	0.6		
8	Cement water factor Used	0.54		
9	Slump	60-180	mm	be appointed
10	Maximum Aggregate size	20	mm	be appointed
11	Free water content	205		table 3
12	Cement Content	379.630	kg/m3	(11):(8)
13	Maximum cement content	-		
14	Minimum cement content	325		table 4
15	Cement grade used	379.630	kg/m3	
16	Cement water factor adjusted	-		

17	Large arrangement of fine aggregate grains	2		Gradation Zona	
18	Specific gravity of fine aggregate	2.581			
	Specific gravity of coarse aggregate	2.598			
19	% Fine aggregate	42.2	%	figure 13 / 14 / 15	
20	Specific gravity of the combined aggregate	2.591			
21	Concrete Weight	2327	kg/m3	figure 16	
22	Combined aggregate proportions	1742.370	kg/m3	(21)-(15)-(11)	
23	Proportion of fine aggregate	735.280	kg/m3	(19)*(22)	
24	proportion of coarse aggregate	1007.090	kg/m3	(22)-(23)	
No	Description	Cement (kg)	Water (kg)	Aggregate	
				Fine (kg)	Coarse (kg)
25	Theoretical mixture proportions (Aggregate SSD)				
	* Every m3	379.630	205.000	735.280	1007.090
	* Each test mixture (1 samples) : 0,02651 m3	20.126	10.868	38.980	53.390
26	Mix proportions with shrinkage figures (20%)				
	* Every m3	455.556	246.000	882.336	1208.508
	* Each test mixture (10 samples) : 0,05301 m3	24.151	13.042	46.777	64.068
	Ratio	1	0.540	1.937	2.653

Appendix 4. Compressive test

Conversion Rate for the age of Specimen

Specimen Form	Age of Specimen	Conversion Rate
Cylindrical 150x300 mm	14 days	0.88

Specimen Data with 0% glass powder

Specimen

Dimension

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Diameter	150	150	150	mm
Hight	298	300	310	mm
wight of specimen	12.70	12.60	12.80	kg
cross-sectional area	17671.4 6	17671.4 6	17671.46	mm ²

Test Data

Description	Cylinder 1	Cylinder 2	Cylinde r 3	Unit
Maximum Load	380.67	372.9	494.12	kn
Long test	36	39	46	Seconds

Compressive Stringth	21.54	21.10	27.96	Mpa
Average			23.53	

Specimen Data with 10% glass powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Diameter	150	150	150	mm
Hight	299	310	300	mm
wight of specimen	12.53	12.63	12.67	kg
cross-sectional area	17671.46	17671.46	17671.46	mm ²

Test Data

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Maximum Load	451.36	477.68	397.99	kn
Long test	44	45	39	Seconds
Compressive Stringth	25.54	27.03	22.52	Mpa
Average			25.03	

Specimen Data with 15% glass powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Diameter	150	150	150	mm

Hight	330	330	320	mm
wight of specimen	12.713	12.661	12.583	kg
cross-sectional area	17671.46	17671.46	17671.46	mm2

Test Data

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Maximum Load	347.54	420.44	518.12	kn
Long test	39	40	51	Seconds
Compressive Stringth	19.66	23.79	29.31	Mpa
Average			24.25	

Specimen Data with 20% glass powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Diameter	150	150	150	mm
Hight	299	300	330	mm
wight of specimen	12.687	12.673	12.599	kg
cross-sectional area	17671.46	17671.46	17671.46	mm2

Test Data

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Maximum Load	569.7	611.99	426.74	kn
Long test	54	58	42	Seconds
Compressive Stringth	32.23	34.63	24.14	Mpa
Average			30.33	

Specimen Data with 25% glass powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Diameter	150	150	150	mm
Hight	300	300	320	mm
wight of specimen	12.285	12.129	12.279	kg
cross-sectional area	17671.46	17671.46	17671.46	mm ²

Test Data

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Maximum Load	407.97	451.02	439.12	kn
Long test	39	43	42	Seconds
Compressive Stringth	23.08	25.52	24.84	Mpa
Average			24.48	

Specimen Data with 30% glass powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Unit
Diameter	150	150	150	mm
Hight	300	300	299	mm
wight of specimen	12.352	12.333	12.248	kg
cross-sectional area	17671.4 6	17671.4 6	17671.46	mm ²

Test Data

Description	Cylinde r 1	Cylinde r 2	Cylinde r 3	Unit
Maximum Load	402.36	445.36	444.89	kn
Long test	39	43	42	Seconds
Compressive Stringth	22.76	25.20	25.17	Mpa
Average			24.38	

No.	Variation	Average
1	0%	23.53
2	10%	25.03
3	15%	24.26
4	20%	30.34
5	25%	24.49
6	30%	24.38

Appendix 5. Splitting Tensile Strength Test

Conversion Rate for the age of Specimen

Specimen Form	Age of Specimen	Conversion Rate
Cylindrical 150x300 mm	14 days	0.88

Specimen Data with 0% glass powder

Specimen

Dimension

Description	Cylinder r 1	Cylinder r 2	Cylinder 3	Cylinder r 4	Cylinder r 5	Unit
Diameter	150	150	150	150	150	mm
Hight	300	300	300	300	300	mm
wight of specimen	12.7	12.9	12.8	12.7	12.9	kg

Test Data

Description	Cylinder r 1	Cylinder r 2	Cylinder r 3	Cylinder r 4	Cylinder r 5	Unit
Maximum Load	111	110	99	104	93	KN
Tensile Strength Test	1.570	1.556	1.401	1.471	1.316	Mpa
Average					1.46	

Specimen Data with 10% glass powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Diameter	150	150	150	150	150	mm
Height	320	310	299	299	300	mm
Weight of specimen	12.7	12.7	12.6	12.4	12.4	kg

Test Data

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Maximum Load	98	119	100	100	115	KN
Tensile Strength Test	1.300	1.629	1.419	1.419	1.627	Mpa
Average					1.47	

Specimen Data with 15% glass powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Diameter	150	150	150	150	150	mm
Height	330	330	300	300	320	mm
Weight of specimen	12.666	12.683	12.583	12.615	12.675	kg

Test Data

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Maximum Load	123	105	125	91	103	KN
Long test						Seconds
Tensile Strength Test	1.58	1.35	1.76	1.28	1.36	Mpa
Average					1.471	

Specimen Data with 20% glass powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Diameter	150	150	150	150	150	mm
Hight	330	299	300	320	300	mm
wight of specimen	12.709	12.561	12.182	12.737	12.47	kg

Test Data

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Maximum Load	122	102	115	108	116	KN
Tensile Strength Test	1.56	1.44	1.62	1.43	1.64	Mpa
Average					1.543	

Specimen Data with 25% glass powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Diameter	150	150	150	150	150	mm
Hight	310	330	300	300	320	mm
wight of specimen	12.281	12.364	12.23	12.063	12.401	kg

Test Data

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Maximum Load	106	124	112	90	116	KN
Tensile Strength Test	1.451219	1.594765	1.584476	1.27324	1.538498	Mpa
Average					1.488	

Specimen Data with 30% glass powder

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Diameter	150	150	150	150	150	mm
Hight	300	300	300	300	330	mm
wight of specimen	12.127	12.525	12.5	12.467	12.357	kg

Test Data

Description	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Unit
Maximum Load	120	98	115	98	100	KN
Tensile Strength Test	1.69	1.38	1.62	1.38	1.28	Mpa
Average						1.47

NO.	Variatio n	Averag e
1	0%	1.46
2	10%	1.47
3	15%	1.47
4	20%	1.54
5	25%	1.48
6	30%	1.47

Appendix 6. Elasticity Modulus

Specimen Data with 0% glass powder

Description	Cylinder 1	Cylinder 2	Unit
Diameter	150	150	mm
Hight	300	300	mm
wight of specimen	12.56	12.75	kg
cross-sectional area	17671.4 6	17671.4 6	mm ²

Test Data

Description	Cylinde r 1	Cylinde r 2	Unit
Maximum Load	479.4	491.8	KN
Test Duration	489	337	Seconds
Modulus Test	27.13	27.83	Mpa
	Average		27.48

Specimen Data with 10% glass powder

Description	Cylinder 1	Cylinder 2	Unit
Diameter	150	150	mm
Hight	299	300	mm

wight of specimen	12.45	12.68	kg
cross-sectional area	17671.5	17671.5	mm2

Test Data

Description	Cylinder r 1	Cylinder r 2	Unit
Maximum Load	340.6	436.3	KN
Test Duration	242	309	Seconds
Modulus Test	19.27	24.69	Mpa
	Average	21.98	

Specimen Data with 15% glass powder

Description	Cylinder 1	Cylinder 2	Unit
Diameter	150	150	mm
Hight	300	330	mm
wight of specimen	12.70	12.65	kg
cross-sectional area	17671.4 6	17671.4 6	mm2

Test Data

Description	Cylinder r 1	Cylinder r 2	Unit
Maximum Load	428.2	561.6	KN
Test Duration	211	158	Seconds

Modulus Test	24.23	31.78	Mpa
	Average	28.01	

Specimen Data with 20% glass powder

Description	Cylinder 1	Cylinder 2	Unit
Diameter	150	150	mm
Hight	300	300	mm
wight of specimen	12.37	12.71	kg
cross-sectional area	17671.5	17671.5	mm2

Test Data

Description	Cylinde r 1	Cylinde r 2	Unit
Maximum Load	559.3	607.6	KN
Test Duration	162	136	Seconds
Modulus Test	31.65	34.38	Mpa
	Average	33.02	

Specimen Data with 25% glass powder

Description	Cylinder 1	Cylinder 2	Unit
Diameter	150	150	mm
Hight	300	310	mm
wight of specimen	12.15	12.17	kg

cross-sectional area	17671.4 6	17671.4 6	mm ²
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Test Data

Description	Cylinder 1	Cylinder 2	Unit
Maximum Load	459.6	460.6	KN
Test Duration	159	86	Seconds
Modulus Test	26.01	26.06	Mpa
	Average		26.04

Specimen Data with 30% glass powder

Description	Cylinder 1	Cylinder 2	Unit
Diameter	150	150	mm
Hight	300	300	mm
wight of specimen	12.54	12.22	kg
cross-sectional area	17671.5	17671.5	mm ²

Test Data

Description	Cylinder 1	Cylinder 2	Unit
Maximum Load	354.6	392.1	KN
Test Duration	133	138	Seconds

Modulus Test	20.07	22.19	Mpa
		Average	21.13

0% glass powder, cylinder1					
Load (kN)	Dial record	Load (N)	Actual $\Delta L(1/2\Delta L)(mm)$	Strain($\Delta L/L_0$)(mm)	Tension(P/A)(Mpa)(stress)
10	1	10000	0.0005	0.000002	0.565884242
20	7	20000	0.0035	0.000012	1.131768484
30	13	30000	0.0065	0.000022	1.697652726
40	19	40000	0.0095	0.000032	2.263536968
50	26	50000	0.013	0.000043	2.829421211
60	34	60000	0.017	0.000057	3.395305453
70	39	70000	0.0195	0.000065	3.961189695
80	46	80000	0.023	0.000077	4.527073937
90	53	90000	0.0265	0.000088	5.092958179
100	60	100000	0.03	0.000100	5.658842421
110	67	110000	0.0335	0.000112	6.224726663
120	74	120000	0.037	0.000123	6.790610905
130	82	130000	0.041	0.000137	7.356495147
140	90	140000	0.045	0.000150	7.922379389
150	99	150000	0.0495	0.000165	8.488263632
160	109	160000	0.0545	0.000182	9.054147874
170	118	170000	0.059	0.000197	9.620032116
180	128	180000	0.064	0.000213	10.18591636
190	137	190000	0.0685	0.000228	10.7518006
200	148	200000	0.074	0.000247	11.31768484
210	159	210000	0.0795	0.000265	11.88356908
220	169	220000	0.0845	0.000282	12.44945333
230	180	230000	0.09	0.000300	13.01533757

240	190	240000	0.095	0.000317	13.58122181
250	203	250000	0.1015	0.000338	14.14710605
260	215	260000	0.1075	0.000358	14.71299029
270	228	270000	0.114	0.000380	15.27887454
280	240	280000	0.12	0.000400	15.84475878
290	254	290000	0.127	0.000423	16.41064302
300	267	300000	0.1335	0.000445	16.97652726
310	281	310000	0.1405	0.000468	17.54241151
320	295	320000	0.1475	0.000492	18.10829575
330	310	330000	0.155	0.000517	18.67417999
340	326	340000	0.163	0.000543	19.24006423
350	342	350000	0.171	0.000570	19.80594847
360	360	360000	0.18	0.000600	20.37183272
370	377	370000	0.1885	0.000628	20.93771696
380	395	380000	0.1975	0.000658	21.5036012
390	415	390000	0.2075	0.000692	22.06948544
400	436	400000	0.218	0.000727	22.63536968
410	460	410000	0.23	0.000767	23.20125393
420	485	420000	0.2425	0.000808	23.76713817
430	512	430000	0.256	0.000853	24.33302241
440	540	440000	0.27	0.000900	24.89890665
450	570	450000	0.285	0.000950	25.46479089
460	604	460000	0.302	0.001007	26.03067514
470	644	470000	0.322	0.001073	26.59655938
479.4	685	479400	0.3425	0.001142	27.12849057
470	879	470000	0.4395	0.001465	26.59655938

460	924	460000	0.462	0.001540	26.03067514
450	960	450000	0.48	0.001600	25.46479089
440	988	440000	0.494	0.001647	24.89890665
430	1013	430000	0.5065	0.001688	24.33302241
420	1030	420000	0.515	0.001717	23.76713817
410	1051	410000	0.5255	0.001752	23.20125393

S2	10.75	
	0.00022833	
S1	1.8674	
Ec=	39816.47	Mpa

0% glass powder, cylinder2					
Load (kN)	Dial record	Load (N)	Actual $\Delta L(1/2\Delta L)(mm)$	Strain($\Delta L/L_0$)(mm)	Tension(P/A)(Mpa)(stress)
10	1	10000	0.0005	0.000002	0.56588424
20	9	20000	0.0045	0.000015	1.13176848
30	16	30000	0.008	0.000027	1.69765273
40	24	40000	0.012	0.000040	2.26353697
50	33	50000	0.0165	0.000055	2.82942121
60	40	60000	0.02	0.000067	3.39530545
70	48	70000	0.024	0.000080	3.96118969
80	56	80000	0.028	0.000093	4.52707394
90	65	90000	0.0325	0.000108	5.09295818
100	74	100000	0.037	0.000123	5.65884242

110	83	110000	0.0415	0.000138	6.22472666
120	90	120000	0.045	0.000150	6.79061091
130	99	130000	0.0495	0.000165	7.35649515
140	108	140000	0.054	0.000180	7.92237939
150	118	150000	0.059	0.000197	8.48826363
160	128	160000	0.064	0.000213	9.05414787
170	138	170000	0.069	0.000230	9.62003212
180	146	180000	0.073	0.000243	10.1859164
190	154	190000	0.077	0.000257	10.7518006
200	163	200000	0.0815	0.000272	11.3176848
210	172	210000	0.086	0.000287	11.8835691
220	180	220000	0.09	0.000300	12.4494533
230	191	230000	0.0955	0.000318	13.0153376
240	199	240000	0.0995	0.000332	13.5812218
250	209	250000	0.1045	0.000348	14.1471061
260	220	260000	0.11	0.000367	14.7129903
270	228	270000	0.114	0.000380	15.2788745
280	238	280000	0.119	0.000397	15.8447588
290	249	290000	0.1245	0.000415	16.410643
300	260	300000	0.13	0.000433	16.9765273
310	271	310000	0.1355	0.000452	17.5424115
320	281	320000	0.1405	0.000468	18.1082957
330	292	330000	0.146	0.000487	18.67418
340	304	340000	0.152	0.000507	19.2400642
350	315	350000	0.1575	0.000525	19.8059485
360	328	360000	0.164	0.000547	20.3718327

370	342	370000	0.171	0.000570	20.937717
380	355	380000	0.1775	0.000592	21.5036012
390	369	390000	0.1845	0.000615	22.0694854
400	385	400000	0.1925	0.000642	22.6353697
410	402	410000	0.201	0.000670	23.2012539
420	418	420000	0.209	0.000697	23.7671382
430	437	430000	0.2185	0.000728	24.3330224
440	457	440000	0.2285	0.000762	24.8989067
450	480	450000	0.24	0.000800	25.4647909
460	505	460000	0.2525	0.000842	26.0306751
470	534	470000	0.267	0.000890	26.5965594
480	575	480000	0.2875	0.000958	27.1624436
490	640	490000	0.32	0.001067	27.7283279
491.8	664	491800	0.332	0.001107	27.830187
490	710	490000	0.355	0.001183	27.7283279
480	785	480000	0.3925	0.001308	27.1624436
470	851	470000	0.4255	0.001418	26.5965594
460	899	460000	0.4495	0.001498	26.0306751
450	940	450000	0.47	0.001567	25.4647909
440	975	440000	0.4875	0.001625	24.8989067
430	1007	430000	0.5035	0.001678	24.3330224
420	1035	420000	0.5175	0.001725	23.7671382

S2	11.32	
	0.00027167	
S1	1.9240	
E _c =	35252.73	Mpa

10% glass powder, cylinder1					
Load (kN)	Dial record	Load (N)	Actual $\Delta L(1/2\Delta L)(mm)$	Strain($\Delta L/L_0$)(m m)	Tension(P/A)(Mpa)(stres s)
10	3	10000	0.0015	0.000005	0.565884242
20	10	20000	0.005	0.000017	1.131768484
30	16	30000	0.008	0.000027	1.697652726
40	23	40000	0.0115	0.000038	2.263536968
50	30	50000	0.015	0.000050	2.829421211
60	37	60000	0.0185	0.000062	3.395305453
70	43	70000	0.0215	0.000072	3.961189695
80	49	80000	0.0245	0.000082	4.527073937
90	56	90000	0.028	0.000094	5.092958179
100	63	100000	0.0315	0.000105	5.658842421
110	69	110000	0.0345	0.000115	6.224726663
120	77	120000	0.0385	0.000129	6.790610905
130	84	130000	0.042	0.000140	7.356495147
140	90	140000	0.045	0.000151	7.922379389
150	99	150000	0.0495	0.000166	8.488263632
160	106	160000	0.053	0.000177	9.054147874

170	114	170000	0.057	0.000191	9.620032116
180	122	180000	0.061	0.000204	10.18591636
190	129	190000	0.0645	0.000216	10.7518006
200	137	200000	0.0685	0.000229	11.31768484
210	144	210000	0.072	0.000241	11.88356908
220	152	220000	0.076	0.000254	12.44945333
230	160	230000	0.08	0.000268	13.01533757
240	169	240000	0.0845	0.000283	13.58122181
250	178	250000	0.089	0.000298	14.14710605
260	186	260000	0.093	0.000311	14.71299029
270	196	270000	0.098	0.000328	15.27887454
280	204	280000	0.102	0.000341	15.84475878
290	214	290000	0.107	0.000358	16.41064302
300	227	300000	0.1135	0.000380	16.97652726
310	240	310000	0.12	0.000401	17.54241151
320	255	320000	0.1275	0.000426	18.10829575
330	273	330000	0.1365	0.000457	18.67417999
340.6	303	340600	0.1515	0.000507	19.27401729
330	351	330000	0.1755	0.000587	18.67417999
320	372	320000	0.186	0.000622	18.10829575
310	386	310000	0.193	0.000645	17.54241151
300	402	300000	0.201	0.000672	16.97652726
290	472	290000	0.236	0.000789	16.41064302

S2	7.92	
	0.00015050	
S1	2.8294	
E _c =	35050.93	Mpa

10% glass powder, cylinder2					
Load (kN)	Dial record	Load (N)	Actual $\Delta L(1/2\Delta L)(mm)$	Strain($\Delta L/L_0$)(mm)	Tension(P/A)(Mpa)(stress)
10	3	10000	0.0015	0.000005	0.565884242
20	10	20000	0.005	0.000017	1.131768484
30	18	30000	0.009	0.000030	1.697652726
40	27	40000	0.0135	0.000045	2.263536968
50	34	50000	0.017	0.000057	2.829421211
60	41	60000	0.0205	0.000068	3.395305453
70	49	70000	0.0245	0.000082	3.961189695
80	58	80000	0.029	0.000097	4.527073937
90	65	90000	0.0325	0.000108	5.092958179
100	74	10000 0	0.037	0.000123	5.658842421
110	82	11000 0	0.041	0.000137	6.224726663
120	91	12000 0	0.0455	0.000152	6.790610905
130	99	13000 0	0.0495	0.000165	7.356495147

140	107	14000 0	0.0535	0.000178	7.922379389
150	116	15000 0	0.058	0.000193	8.488263632
160	125	16000 0	0.0625	0.000208	9.054147874
170	134	17000 0	0.067	0.000223	9.620032116
180	145	18000 0	0.0725	0.000242	10.18591636
190	154	19000 0	0.077	0.000257	10.7518006
200	164	20000 0	0.082	0.000273	11.31768484
210	172	21000 0	0.086	0.000287	11.88356908
220	182	22000 0	0.091	0.000303	12.44945333
230	191	23000 0	0.0955	0.000318	13.01533757
240	202	24000 0	0.101	0.000337	13.58122181
250	211	25000 0	0.1055	0.000352	14.14710605
260	222	26000 0	0.111	0.000370	14.71299029
270	233	27000 0	0.1165	0.000388	15.27887454

280	245	28000 0	0.1225	0.000408	15.84475878
290	258	29000 0	0.129	0.000430	16.41064302
300	269	30000 0	0.1345	0.000448	16.97652726
310	280	31000 0	0.14	0.000467	17.54241151
320	289	32000 0	0.1445	0.000482	18.10829575
330	300	33000 0	0.15	0.000500	18.67417999
340	312	34000 0	0.156	0.000520	19.24006423
350	324	35000 0	0.162	0.000540	19.80594847
360	340	36000 0	0.17	0.000567	20.37183272
370	354	37000 0	0.177	0.000590	20.93771696
380	372	38000 0	0.186	0.000620	21.5036012
390	391	39000 0	0.1955	0.000652	22.06948544
400	410	40000 0	0.205	0.000683	22.63536968
410	428	41000 0	0.214	0.000713	23.20125393

420	453	42000 0	0.2265	0.000755	23.76713817
430	490	43000 0	0.245	0.000817	24.33302241
436.3	516	43630 0	0.258	0.000860	24.68952948
430	633	43000 0	0.3165	0.001055	24.33302241
420	695	42000 0	0.3475	0.001158	23.76713817
410	746	41000 0	0.373	0.001243	23.20125393
400	847	40000 0	0.4235	0.001412	22.63536968
390	960	39000 0	0.48	0.001600	22.06948544
380	1057	38000 0	0.5285	0.001762	21.5036012

S2	9.62003	
	0.00022333	
S1	1.8674	
Ec=	35540.71	Mpa

15% glass powder, cylinder1					
Load (kN)	Dial record	Load (N)	Actual $\Delta L(1/2\Delta L)(mm)$	Strain($\Delta L/L_0$)(mm)	Tension(P/A)(Mpa)(stress)
10	2	10000	0.001	0.000003	0.57
20	14	20000	0.007	0.000023	1.13
30	22	30000	0.011	0.000037	1.70
40	34	40000	0.017	0.000057	2.26
50	44	50000	0.022	0.000073	2.83
60	55	60000	0.0275	0.000092	3.40
70	64	70000	0.032	0.000107	3.96
80	77	80000	0.0385	0.000128	4.53
90	86	90000	0.043	0.000143	5.09
100	98	100000	0.049	0.000163	5.66
110	109	110000	0.0545	0.000182	6.22
120	121	120000	0.0605	0.000202	6.79
130	132	130000	0.066	0.000220	7.36
140	143	140000	0.0715	0.000238	7.92
150	156	150000	0.078	0.000260	8.49
160	167	160000	0.0835	0.000278	9.05
170	182	170000	0.091	0.000303	9.62
180	194	180000	0.097	0.000323	10.19
190	207	190000	0.1035	0.000345	10.75
200	221	200000	0.1105	0.000368	11.32
210	235	210000	0.1175	0.000392	11.88
220	248	220000	0.124	0.000413	12.45

230	258	230000	0.129	0.000430	13.02
240	271	240000	0.1355	0.000452	13.58
250	285	250000	0.1425	0.000475	14.15
260	296	260000	0.148	0.000493	14.71
270	310	270000	0.155	0.000517	15.28
280	324	280000	0.162	0.000540	15.84
290	340	290000	0.17	0.000567	16.41
300	353	300000	0.1765	0.000588	16.98
310	368	310000	0.184	0.000613	17.54
320	383	320000	0.1915	0.000638	18.11
330	399	330000	0.1995	0.000665	18.67
340	406	340000	0.203	0.000677	19.24
350	436	350000	0.218	0.000727	19.81
360	456	360000	0.228	0.000760	20.37
370	476	370000	0.238	0.000793	20.94
380	498	380000	0.249	0.000830	21.50
390	524	390000	0.262	0.000873	22.07
400	559	400000	0.2795	0.000932	22.64
410	609	410000	0.3045	0.001015	23.20
420	668	420000	0.334	0.001113	23.77
428.2	764	428200	0.382	0.001273	24.23
420	856	420000	0.428	0.001427	23.77
410	922	410000	0.461	0.001537	23.20
400	1002	400000	0.501	0.001670	22.64
390	1069	390000	0.5345	0.001782	22.07
380	1126	380000	0.563	0.001877	21.50

370	1161	370000	0.5805	0.001935	20.94
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S2	9.69247	
	0.00030333	
S1	1.527887454	
Ec=	27385.66	Mpa

15% glass powder, cylinder2					
Load (kN)	Dial record	Load (N)	Actual $\Delta L(1/2\Delta L)(mm)$	Strain($\Delta L/L_0$)(mm)	Tension(P/A)(Mpa)(stress)
10	1	10000	0.0005	0.000002	0.57
20	9	20000	0.0045	0.000015	1.13
30	17	30000	0.0085	0.000028	1.70
40	24	40000	0.012	0.000040	2.26
50	34	50000	0.017	0.000057	2.83
60	41	60000	0.0205	0.000068	3.40
70	50	70000	0.025	0.000083	3.96
80	59	80000	0.0295	0.000098	4.53
90	69	90000	0.0345	0.000115	5.09
100	78	100000	0.039	0.000130	5.66
110	88	110000	0.044	0.000147	6.22
120	94	120000	0.047	0.000157	6.79
130	106	130000	0.053	0.000177	7.36
140	114	140000	0.057	0.000190	7.92

150	123	150000	0.0615	0.000205	8.49
160	134	160000	0.067	0.000223	9.05
170	143	170000	0.0715	0.000238	9.62
180	153	180000	0.0765	0.000255	10.19
190	162	190000	0.081	0.000270	10.75
200	174	200000	0.087	0.000290	11.32
210	185	210000	0.0925	0.000308	11.88
220	197	220000	0.0985	0.000328	12.45
230	206	230000	0.103	0.000343	13.02
240	217	240000	0.1085	0.000362	13.58
250	229	250000	0.1145	0.000382	14.15
260	240	260000	0.12	0.000400	14.71
270	254	270000	0.127	0.000423	15.28
280	265	280000	0.1325	0.000442	15.84
290	280	290000	0.14	0.000467	16.41
300	291	300000	0.1455	0.000485	16.98
310	305	310000	0.1525	0.000508	17.54
320	319	320000	0.1595	0.000532	18.11
330	332	330000	0.166	0.000553	18.67
340	346	340000	0.173	0.000577	19.24
350	361	350000	0.1805	0.000602	19.81
360	377	360000	0.1885	0.000628	20.37
370	393	370000	0.1965	0.000655	20.94
380	409	380000	0.2045	0.000682	21.50
390	427	390000	0.2135	0.000712	22.07
400	441	400000	0.2205	0.000735	22.64

410	461	410000	0.2305	0.000768	23.20
420	479	420000	0.2395	0.000798	23.77
430	498	430000	0.249	0.000830	24.33
440	519	440000	0.2595	0.000865	24.90
450	536	450000	0.268	0.000893	25.46
460	556	460000	0.278	0.000927	26.03
470	579	470000	0.2895	0.000965	26.60
470	601	470000	0.3005	0.001002	26.60
490	626	490000	0.313	0.001043	27.73
500	652	500000	0.326	0.001087	28.29
510	683	510000	0.3415	0.001138	28.86
520	716	520000	0.358	0.001193	29.43
530	749	530000	0.3745	0.001248	29.99
540	792	540000	0.396	0.001320	30.56
550	848	550000	0.424	0.001413	31.12
560	941	560000	0.4705	0.001568	31.69
561.6	962	561600	0.481	0.001603	31.78
560	1050	560000	0.525	0.001750	31.69
550	1136	550000	0.568	0.001893	31.12
540	1178	540000	0.589	0.001963	30.56
530	1210	530000	0.605	0.002017	29.99
520	1250	520000	0.625	0.002083	29.43
510	1285	510000	0.6425	0.002142	28.86
500	1320	500000	0.66	0.002200	28.29
490	1360	490000	0.68	0.002267	27.73

S2	12.71202	
	0.00032833	
S1	1.75424115	
Ec=	33911.02	Mpa

20% glass powder, cylinder1					
Load (kN)	Dial record	Load (N)	Actual $\Delta L(1/2\Delta L)(mm)$	Strain($\Delta L/L_0$)(mm)	Tension(P/A)(Mpa)(stress)
10	6	10000	0.003	0.000010	0.57
20	12	20000	0.006	0.000020	1.13
30	22	30000	0.011	0.000037	1.70
40	31	40000	0.0155	0.000052	2.26
50	41	50000	0.0205	0.000068	2.83
60	52	60000	0.026	0.000087	3.40
70	63	70000	0.0315	0.000105	3.96
80	73	80000	0.0365	0.000122	4.53
90	83	90000	0.0415	0.000138	5.09
100	94	10000 0	0.047	0.000157	5.66
110	103	11000 0	0.0515	0.000172	6.22
120	115	12000 0	0.0575	0.000192	6.79
130	124	13000 0	0.062	0.000207	7.36

140	136	14000 0	0.068	0.000227	7.92
150	145	15000 0	0.0725	0.000242	8.49
160	157	16000 0	0.0785	0.000262	9.05
170	166	17000 0	0.083	0.000277	9.62
180	174	18000 0	0.087	0.000290	10.19
190	188	19000 0	0.094	0.000313	10.75
200	199	20000 0	0.0995	0.000332	11.32
210	208	21000 0	0.104	0.000347	11.88
220	220	22000 0	0.11	0.000367	12.45
230	229	23000 0	0.1145	0.000382	13.02
240	240	24000 0	0.12	0.000400	13.58
250	251	25000 0	0.1255	0.000418	14.15
260	262	26000 0	0.131	0.000437	14.71
270	273	27000 0	0.1365	0.000455	15.28

280	286	28000 0	0.143	0.000477	15.84
290	296	29000 0	0.148	0.000493	16.41
300	305	30000 0	0.1525	0.000508	16.98
310	316	31000 0	0.158	0.000527	17.54
320	325	32000 0	0.1625	0.000542	18.11
330	337	33000 0	0.1685	0.000562	18.67
340	346	34000 0	0.173	0.000577	19.24
350	358	35000 0	0.179	0.000597	19.81
360	368	36000 0	0.184	0.000613	20.37
370	380	37000 0	0.19	0.000633	20.94
380	391	38000 0	0.1955	0.000652	21.50
390	402	39000 0	0.201	0.000670	22.07
400	416	40000 0	0.208	0.000693	22.64
410	428	41000 0	0.214	0.000713	23.20

420	441	42000 0	0.2205	0.000735	23.77
430	454	43000 0	0.227	0.000757	24.33
440	469	44000 0	0.2345	0.000782	24.90
450	482	45000 0	0.241	0.000803	25.46
460	498	46000 0	0.249	0.000830	26.03
470	515	47000 0	0.2575	0.000858	26.60
480	531	48000 0	0.2655	0.000885	27.16
490	549	49000 0	0.2745	0.000915	27.73
500	567	50000 0	0.2835	0.000945	28.29
510	587	51000 0	0.2935	0.000978	28.86
520	609	52000 0	0.3045	0.001015	29.43
530	633	53000 0	0.3165	0.001055	29.99
540	664	54000 0	0.332	0.001107	30.56
550	701	55000 0	0.3505	0.001168	31.12

559.3	769	55930 0	0.3845	0.001282	31.65
550	819	55000 0	0.4095	0.001365	31.12
540	843	54000 0	0.4215	0.001405	30.56
530	864	53000 0	0.432	0.001440	29.99
520	881	52000 0	0.4405	0.001468	29.43
510	899	51000 0	0.4495	0.001498	28.86
500	914	50000 0	0.457	0.001523	28.29
490	929	49000 0	0.4645	0.001548	27.73
480	938	48000 0	0.469	0.001563	27.16

S2	12.65996	
	0.00036667	
S1	1.697652726	
Ec=	30327.30	Mpa

20% glass powder, cylinder2

Load (kN)	Dial record	Load (N)	Actual $\Delta L(1/2\Delta L)(mm)$	Strain($\Delta L/L_0$)(mm)	Tension(P/A)(Mpa)(stress)
10	1	10000	0.0005	0.000002	0.57
20	6	20000	0.003	0.000010	1.13
30	11	30000	0.0055	0.000018	1.70
40	19	40000	0.0095	0.000032	2.26
50	22	50000	0.011	0.000037	2.83
60	31	60000	0.0155	0.000052	3.40
70	38	70000	0.019	0.000063	3.96
80	42	80000	0.021	0.000070	4.53
90	48	90000	0.024	0.000080	5.09
100	58	100000	0.029	0.000097	5.66
110	67	110000	0.0335	0.000112	6.22
120	74	120000	0.037	0.000123	6.79
130	82	130000	0.041	0.000137	7.36
140	90	140000	0.045	0.000150	7.92
150	99	150000	0.0495	0.000165	8.49
160	108	160000	0.054	0.000180	9.05
170	117	170000	0.0585	0.000195	9.62
180	128	180000	0.064	0.000213	10.19
190	136	190000	0.068	0.000227	10.75
200	143	200000	0.0715	0.000238	11.32
210	154	210000	0.077	0.000257	11.88
220	162	220000	0.081	0.000270	12.45
230	171	230000	0.0855	0.000285	13.02
240	184	240000	0.092	0.000307	13.58

250	197	250000	0.0985	0.000328	14.15
260	205	260000	0.1025	0.000342	14.71
270	216	270000	0.108	0.000360	15.28
280	224	280000	0.112	0.000373	15.84
290	237	290000	0.1185	0.000395	16.41
300	248	300000	0.124	0.000413	16.98
310	259	310000	0.1295	0.000432	17.54
320	277	320000	0.1385	0.000462	18.11
330	284	330000	0.142	0.000473	18.67
340	294	340000	0.147	0.000490	19.24
350	308	350000	0.154	0.000513	19.81
360	320	360000	0.16	0.000533	20.37
370	331	370000	0.1655	0.000552	20.94
380	342	380000	0.171	0.000570	21.50
390	352	390000	0.176	0.000587	22.07
400	363	400000	0.1815	0.000605	22.64
410	376	410000	0.188	0.000627	23.20
420	386	420000	0.193	0.000643	23.77
430	399	430000	0.1995	0.000665	24.33
440	410	440000	0.205	0.000683	24.90
450	422	450000	0.211	0.000703	25.46
460	436	460000	0.218	0.000727	26.03
470	449	470000	0.2245	0.000748	26.60
480	464	480000	0.232	0.000773	27.16
490	479	490000	0.2395	0.000798	27.73
500	494	500000	0.247	0.000823	28.29

510	508	510000	0.254	0.000847	28.86
520	525	520000	0.2625	0.000875	29.43
530	547	530000	0.2735	0.000912	29.99
540	565	540000	0.2825	0.000942	30.56
550	589	550000	0.2945	0.000982	31.12
560	610	560000	0.305	0.001017	31.69
570	622	570000	0.311	0.001037	32.26
580	649	580000	0.3245	0.001082	32.82
590	694	590000	0.347	0.001157	33.39
600	762	600000	0.381	0.001270	33.95
606.7	889	606700	0.4445	0.001482	34.33
600	951	600000	0.4755	0.001585	33.95
590	992	590000	0.496	0.001653	33.39
580	1042	580000	0.521	0.001737	32.82
570	1066	570000	0.533	0.001777	32.26
560	1094	560000	0.547	0.001823	31.69

S2	13.73288	
	0.00030667	
S1	3.40	
Ec=	34290.93	Mpa

25% glass powder,
cylinder1

Load (kN)	Dial record	Load (N)	Actual $\Delta L(1/2\Delta L)(mm)$	Strain($\Delta L/L_0$)(mm)	Tension(P/A)(Mpa)(stress)
10	1	10000	0.0005	0.000002	0.57
20	9	20000	0.0045	0.000015	1.13
30	13	30000	0.0065	0.000022	1.70
40	19	40000	0.0095	0.000032	2.26
50	28	50000	0.014	0.000047	2.83
60	32	60000	0.016	0.000053	3.40
70	39	70000	0.0195	0.000065	3.96
80	48	80000	0.024	0.000080	4.53
90	56	90000	0.028	0.000093	5.09
100	63	100000	0.0315	0.000105	5.66
110	73	110000	0.0365	0.000122	6.22
120	82	120000	0.041	0.000137	6.79
130	93	130000	0.0465	0.000155	7.36
140	104	140000	0.052	0.000173	7.92
150	117	150000	0.0585	0.000195	8.49
160	128	160000	0.064	0.000213	9.05
170	140	170000	0.07	0.000233	9.62
180	151	180000	0.0755	0.000252	10.19
190	163	190000	0.0815	0.000272	10.75
200	176	200000	0.088	0.000293	11.32
210	187	210000	0.0935	0.000312	11.88
220	201	220000	0.1005	0.000335	12.45
230	209	230000	0.1045	0.000348	13.02
240	222	240000	0.111	0.000370	13.58

250	238	250000	0.119	0.000397	14.15
260	250	260000	0.125	0.000417	14.71
270	266	270000	0.133	0.000443	15.28
280	279	280000	0.1395	0.000465	15.84
290	296	290000	0.148	0.000493	16.41
300	308	300000	0.154	0.000513	16.98
310	323	310000	0.1615	0.000538	17.54
320	341	320000	0.1705	0.000568	18.11
330	359	330000	0.1795	0.000598	18.67
340	377	340000	0.1885	0.000628	19.24
350	393	350000	0.1965	0.000655	19.81
360	411	360000	0.2055	0.000685	20.37
370	434	370000	0.217	0.000723	20.94
380	457	380000	0.2285	0.000762	21.50
390	479	390000	0.2395	0.000798	22.07
400	501	400000	0.2505	0.000835	22.64
410	531	410000	0.2655	0.000885	23.20
420	564	420000	0.282	0.000940	23.77
430	598	430000	0.299	0.000997	24.33
440	642	440000	0.321	0.001070	24.90
450	690	450000	0.345	0.001150	25.46
459.6	784	459600	0.392	0.001307	26.01
450	878	450000	0.439	0.001463	25.46
440	923	440000	0.4615	0.001538	24.90
430	968	430000	0.484	0.001613	24.33
420	996	420000	0.498	0.001660	23.77

410	1021	410000	0.5105	0.001702	23.20
400	1052	400000	0.526	0.001753	22.64
390	1082	390000	0.541	0.001803	22.07

S2	10.40322	
	0.00025167	
S1	3.40	
Ec=	28433.50	Mpa

25% glass powder, cylinder2					
Load (kN)	Dial record	Load (N)	Actual $\Delta L(1/2\Delta L)(mm)$	Strain($\Delta L/L_0$)(mm)	Tension(P/A)(Mpa)(stress)
10	1	10000	0.0005	0.000002	0.57
20	9	20000	0.0045	0.000015	1.13
30	13	30000	0.0065	0.000022	1.70
40	19	40000	0.0095	0.000032	2.26
50	28	50000	0.014	0.000047	2.83
60	32	60000	0.016	0.000053	3.40
70	39	70000	0.0195	0.000065	3.96
80	48	80000	0.024	0.000080	4.53
90	56	90000	0.028	0.000093	5.09
100	63	100000	0.0315	0.000105	5.66
110	73	110000	0.0365	0.000122	6.22
120	82	120000	0.041	0.000137	6.79
130	93	130000	0.0465	0.000155	7.36

140	104	140000	0.052	0.000173	7.92
150	117	150000	0.0585	0.000195	8.49
160	128	160000	0.064	0.000213	9.05
170	140	170000	0.07	0.000233	9.62
180	151	180000	0.0755	0.000252	10.19
190	163	190000	0.0815	0.000272	10.75
200	176	200000	0.088	0.000293	11.32
210	187	210000	0.0935	0.000312	11.88
220	201	220000	0.1005	0.000335	12.45
230	209	230000	0.1045	0.000348	13.02
240	222	240000	0.111	0.000370	13.58
250	238	250000	0.119	0.000397	14.15
260	250	260000	0.125	0.000417	14.71
270	266	270000	0.133	0.000443	15.28
280	279	280000	0.1395	0.000465	15.84
290	296	290000	0.148	0.000493	16.41
300	308	300000	0.154	0.000513	16.98
310	323	310000	0.1615	0.000538	17.54
320	341	320000	0.1705	0.000568	18.11
330	359	330000	0.1795	0.000598	18.67
340	377	340000	0.1885	0.000628	19.24
350	393	350000	0.1965	0.000655	19.81
360	411	360000	0.2055	0.000685	20.37
370	434	370000	0.217	0.000723	20.94
380	457	380000	0.2285	0.000762	21.50
390	479	390000	0.2395	0.000798	22.07

400	501	400000	0.2505	0.000835	22.64
410	531	410000	0.2655	0.000885	23.20
420	564	420000	0.282	0.000940	23.77
430	598	430000	0.299	0.000997	24.33
440	642	440000	0.321	0.001070	24.90
450	690	450000	0.345	0.001150	25.46
460	776	460000	0.388	0.001293	26.03
460.6	786	460600	0.393	0.001310	26.06
460	806	460000	0.403	0.001343	26.03
450	856	450000	0.428	0.001427	25.46
440	892	440000	0.446	0.001487	24.90

S2	10.42585	
	0.00025167	
S1	3.40	
Ec=	28525.34	Mpa

30% glass powder, cylinder1					
Load (kN)	Dial record	Load (N)	Actual $\Delta L(1/2\Delta L)(mm)$	Strain($\Delta L/L_0$)(mm)	Tension(P/A)(Mpa)(stress)
10	2	10000	0.001	0.000003	0.57
20	6	20000	0.003	0.000010	1.13
30	9	30000	0.0045	0.000015	1.70
40	14	40000	0.007	0.000023	2.26

50	21	50000	0.0105	0.000035	2.83
60	29	60000	0.0145	0.000048	3.40
70	34	70000	0.017	0.000057	3.96
80	40	80000	0.02	0.000067	4.53
90	48	90000	0.024	0.000080	5.09
100	54	100000	0.027	0.000090	5.66
110	61	110000	0.0305	0.000102	6.22
120	69	120000	0.0345	0.000115	6.79
130	74	130000	0.037	0.000123	7.36
140	82	140000	0.041	0.000137	7.92
150	91	150000	0.0455	0.000152	8.49
160	99	160000	0.0495	0.000165	9.05
170	108	170000	0.054	0.000180	9.62
180	117	180000	0.0585	0.000195	10.19
190	124	190000	0.062	0.000207	10.75
200	135	200000	0.0675	0.000225	11.32
210	146	210000	0.073	0.000243	11.88
220	159	220000	0.0795	0.000265	12.45
230	172	230000	0.086	0.000287	13.02
240	184	240000	0.092	0.000307	13.58
250	198	250000	0.099	0.000330	14.15
260	213	260000	0.1065	0.000355	14.71
270	233	270000	0.1165	0.000388	15.28
280	252	280000	0.126	0.000420	15.84
290	273	290000	0.1365	0.000455	16.41
300	298	300000	0.149	0.000497	16.98

310	322	310000	0.161	0.000537	17.54
320	358	320000	0.179	0.000597	18.11
330	392	330000	0.196	0.000653	18.67
340	451	340000	0.2255	0.000752	19.24
350	532	350000	0.266	0.000887	19.81
354.6	658	354600	0.329	0.001097	20.07
350	756	350000	0.378	0.001260	19.81
340	820	340000	0.41	0.001367	19.24
330	862	330000	0.431	0.001437	18.67
320	901	320000	0.4505	0.001502	18.11
310	954	310000	0.477	0.001590	17.54
300	981	300000	0.4905	0.001635	16.98

S2	8.02650	
	0.00015167	
S1	1.75	
Ec=	42823.81	Mpa

30% glass powder, cylinder2		Load (N)	Actual $\Delta L(1/2\Delta L)(mm)$	Strain($\Delta L/L_0$)(mm)	Tension(P/A)(Mpa)(stress)
Load (kN)	Dial record				
10	1	10000	0.0005	0.000002	0.57
20	6	20000	0.003	0.000010	1.13
30	13	30000	0.0065	0.000022	1.70
40	19	40000	0.0095	0.000032	2.26

50	29	50000	0.0145	0.000048	2.83
60	37	60000	0.0185	0.000062	3.40
70	42	70000	0.021	0.000070	3.96
80	51	80000	0.0255	0.000085	4.53
90	59	90000	0.0295	0.000098	5.09
100	67	100000	0.0335	0.000112	5.66
110	75	110000	0.0375	0.000125	6.22
120	84	120000	0.042	0.000140	6.79
130	92	130000	0.046	0.000153	7.36
140	101	140000	0.0505	0.000168	7.92
150	111	150000	0.0555	0.000185	8.49
160	120	160000	0.06	0.000200	9.05
170	128	170000	0.064	0.000213	9.62
180	137	180000	0.0685	0.000228	10.19
190	147	190000	0.0735	0.000245	10.75
200	156	200000	0.078	0.000260	11.32
210	165	210000	0.0825	0.000275	11.88
220	176	220000	0.088	0.000293	12.45
230	188	230000	0.094	0.000313	13.02
240	198	240000	0.099	0.000330	13.58
250	209	250000	0.1045	0.000348	14.15
260	218	260000	0.109	0.000363	14.71
270	232	270000	0.116	0.000387	15.28
280	243	280000	0.1215	0.000405	15.84
290	258	290000	0.129	0.000430	16.41
300	272	300000	0.136	0.000453	16.98

310	286	310000	0.143	0.000477	17.54
320	303	320000	0.1515	0.000505	18.11
330	320	330000	0.16	0.000533	18.67
340	338	340000	0.169	0.000563	19.24
350	357	350000	0.1785	0.000595	19.81
360	381	360000	0.1905	0.000635	20.37
370	407	370000	0.2035	0.000678	20.94
380	439	380000	0.2195	0.000732	21.50
390	489	390000	0.2445	0.000815	22.07
392.1	518	392100	0.259	0.000863	22.19
390	528	390000	0.264	0.000880	22.07
380	541	380000	0.2705	0.000902	21.50
370	542	370000	0.271	0.000903	20.94
360	544	360000	0.272	0.000907	20.37
350	568	350000	0.284	0.000947	19.81
340	616	340000	0.308	0.001027	19.24
330	632	330000	0.316	0.001053	18.67

S2	8.87533	
	0.00018500	
S1	1.8108	
Ec=	39290.87	Mpa